Foam

Foam is created by trapping air within a solid or liquid substance. Although culinary foams are most recently associated with molecular gastronomy, they are part of many culinary preparations that date back to even earlier times. Mousse, soufflé, whipped cream, and froth in cappuccino are just some examples of common foams. Common examples of “set” foams are bread, pancakes, and muffins.

Foam does not rely on pressure to encase air bubbles into a substance. Like espuma, foam may also be created with the help of a surfactant and gelling or thickening agents to help it hold shape. The production of a culinary foam starts with a liquid or a solid that has been puréed. The thickening or gelling agent is then diluted into this to form a solution. Once dissolved, the solution is whipped to introduce air into it.

The process of whipping is done until the foam has reached the desired stiffness. Note that certain ingredients may break down if they are whipped for too long, especially without the presence of a stabilizing agent.

Gels

Turning a liquid, such as a vegetable juice or raspberry purée, into a solid not only gives it a different texture but also allows the food to be cut into many shapes, enabling different visual presentations (Figure 2). Regular gelatin can be used as well as other gelling agents, such as agar agar, which is derived from red algae.

Figure 2. *“Papayagelee” by hedonistin is licensed under CC BY NC 2.0*

Brittle gels

Gelling agents are often associated with jelly-like textures, which may range from soft to firm. However, certain gels produced by specific agents may not fit this description.

Rather than forming an elastic or pliable substance, brittle gels may also be formed. These are gels that are firm in nature yet fragile at the same time. This characteristic is caused by the formation of a gel network that is weak and susceptible to breaking. This property allows brittle gels to crumble in the mouth and create a melt-in-the-mouth feeling. As a result, new sensations and textures are experienced while dining. At the same time, tastes within a dish are also enhanced due to the flavour release caused by the gel breakdown.Brittle gels are made by diluting the gelling agent into a liquid substance such as water, milk, or a stock. This mixture is left to set to attain a gelled end product. It should be noted that the concentration of gelling agents used, as well as the amount of liquid, both affect gelation.

Agar agar is a common agent used to create brittle gels. However, when combined with sugar it tends to create a more elastic substance. Low-acyl gellan gum, locust bean gum, and carrageenan also create brittle gels.

Fluid gels

A fluid gel is a cross between a sauce, gel, and purée. It is a controlled liquid that has properties of all three preparations. A fluid gel displays viscosity and fluidity at the same time, being thick yet still spreadable.

Fluid gels behave as solids when undisturbed, and flow when exposed to sufficient agitation. They are used in many culinary dishes where fluids need to be controlled, and they provide a rich, creamy texture.

A fluid gel is created using a base liquid that can come from many different sources. The base liquid is commonly extracted from fruits and vegetables, taken from stocks, or even puréed from certain ingredients. The longer the substance is exposed to stress, and the more intense the outside stress, the more fluidity is gained. More fluidity causes a finer consistency in the gel.

Fluid gels can be served either hot or cold, as many of the gelling agents used for such preparations are stable at high temperatures.

Drying and powdering

Drying a food intensifies its flavour and, of course, changes its texture. Eating a piece of apple that has been cooked and then dehydrated until crisp is very different from eating a fresh fruit slice. If the dehydrated food is powdered, it becomes yet another flavour and texture experience.

When maltodextrin (or tapioca maltodextrin) is mixed with fat, it changes to a powder. Because maltodextrin dissolves in water, peanut butter (or olive oil) that has been changed to a powder changes back to an oil in the mouth.

Freezing

In molecular gastronomy, liquid nitrogen is often used to freeze products or to create a frozen item without the use of a freezer.

Liquid nitrogen is the element nitrogen in a liquefied state. It is a clear, colourless liquid with a temperature of -196°C (-321°F). It is classified as a cryogenic fluid, which causes rapid freezing when it comes into contact with living tissues.

The extremely cold temperatures provided by this liquefied gas are most often used in modern cuisine to produce frozen foams and ice cream. After freezing food, nitrogen boils away, creating a thick nitrogen fog that may also add to the aesthetic features of a dish.

Given the extreme temperature of liquid nitrogen, it must be handled with care. Mishandling may cause serious burns to the skin. Nitrogen must be stored in special flasks and handled only by trained people. Aprons, gloves, and other specially designed safety gear should be used when handling liquid nitrogen.

Used mainly in the form of a coolant for molecular gastronomy, liquid nitrogen is not ingested. It is poured directly onto the food that needs to be cooled, causing it to freeze. Any remaining nitrogen evaporates, although sufficient time must be provided to allow the liquefied gas to be eliminated and for the dish to warm up to the point that it will not cause damage during consumption.

Spherification

Spherification is a modern cuisine technique that involves creating semi-solid spheres with thin membranes out of liquids. Spheres can be made in various sizes and of various firmnesses, such as the “caviar” shown in Figure 3. The result is a burst-in-the-mouth effect, achieved with the liquid. Both flavour and texture are enhanced with this culinary technique.

There are two versions of the spherification process: direct and reverse.

In direct spherification, a flavoured liquid (containing either sodium alginate, gellan gum, or carrageenan) is dripped into a water bath that is mixed with calcium (either calcium chloride or calcium lactate). The outer layer is induced by calcium to form a thin gel layer, leaving a liquid centre. In this version, the spheres are easily breakable and should be consumed immediately.

Calcium chloride and sodium alginate are the two basic components used for this technique. Calcium chloride is a type of salt used in cheese making, and sodium alginate is taken from seaweed. The sodium alginate is used to gel the chosen liquid by dissolving it directly into the fluid. This causes the liquid to become sticky, and proper dissolving must be done by mixing. The liquid is then left to set to eliminate any bubbles.

Once ready, a bath is prepared with calcium chloride and water. The liquid is then dripped into the bath using a spoon or syringe depending on the desired sphere size. The gel forms a membrane encasing the liquid when it comes into contact with the calcium chloride. Once set, the spheres are then removed and rinsed with water to remove any excess calcium chloride.

In reverse spherification, a calcium-containing liquid (or ingredients mixed with a soluble calcium salt) is dripped into a setting bath containing sodium alginate. Surface tension causes the drop to become spherical. A skin of calcium alginate immediately forms around the top. Unlike in the direct version, the gelling stops and does not continue into the liquid orb. This results in thicker shells so the products do not have to be consumed immediately.

Figure 3. *"White chocolate spaghetti with raspberry sauce and chocolate martini caviar" by ayngelina is licensed under CC BY NC-ND 2.0*

Videos on spherification:

Direct: https://www.youtube.com/watch?v=BeRMBv95gLk

Reverse: https://www.youtube.com/watch?v=JPNo79U77yI

Specialty ingredients used in molecular gastronomy

There are a number of different ingredients used in molecular gastronomy as gelling, thickening, or emulsifying agents. Many of these are available in specialty food stores or can be ordered online.

Algin

Another name for sodium alginate, algin is a natural gelling agent taken from the cell walls of certain brown seaweed species.

Calcium chloride

Calcium chloride, also known as $CaCl_2$, is a compound of chlorine and calcium that is a by-product of sodium bicarbonate (baking soda) manufacturing. At room temperature it is a solid salt, which is easily dissolved in water.

This is very salty and is often used for preservation, pickling, cheese production, and adding taste without increasing the amount of sodium. It is also used in molecular gastronomy in the spherification technique (see above) for the production of ravioli, spheres, pearls, and caviar (Figure 3).

Calcium lactate

Calcium lactate is a calcium salt resulting from the fermentation of lactic acid and calcium. It is a white crystalline power when solid and is highly soluble in cold liquids. It is commonly used as a calcium fortifier in various food products including beverages and supplements.

Calcium lactate is also used to regulate acidity levels in cheese and baking powder, as a food thickener, and as a preservative for fresh fruits. In molecular gastronomy, it is most commonly used for basic spherification and reverse spherification due to the lack of bitterness in the finished products.

Like calcium chloride, calcium lactate is used alongside sodium alginate. In regular spherification, it is used in the bath. It is also used as a thickener in reverse spherification.

Carob bean gum

Carob bean gum is another name for locust bean gum. It is often used to stabilize, texturize, thicken, and gel liquids in the area of modern cuisine, although it has been a popular thickener and stabilizer for many years.

Carrageenan

Carrageenan refers to any linear sulfated polysaccharide taken from the extracts of red algae. This seaweed derivative is classified mainly as iota, kappa, and lambda. It is a common ingredient in many foods.

There are a number of purposes that it serves, including binding, thickening, stabilizing, gelling, and emulsifying. Carrageenan can be found in ice cream, salad dressings, cheese, puddings, and many more foods. It is often used with dairy products because of its good interaction with milk proteins. Carrageenan also works well with other common kitchen ingredients and offers a smooth texture and taste that blends well and does not affect flavour.

More often than not, carrageenan is found in powder form, which is hydrated in liquid before being used. For best results, carrageenan powder should be sprinkled in cold liquid and blended well to dissolve, although it may also be melted directly in hot liquids.

Citric acid

Classified as a weak organic acid, citric acid is a naturally occurring preservative that can be found in citrus fruits. Produced as a result of the fermentation of sugar, it has a tart to bitter taste and is usually in powder form when sold commercially. It is used mainly as a preservative and acidulent, and it is a common food additive in a wide range of foods such as candies and soda. Other than extending shelf life by adjusting the acidity or pH of food, it can also help enhance flavours. It works especially well with other fruits, providing a fresh taste.

In modern cooking, citric acid is often used as an emulsifier to keep fats and liquids from separating. It is also a common component in spherification, where it may be used as an acid buffer.

Gellan gum

Gellan gum is a water-soluble, high-molecular-weight polysaccharide gum that is produced through the fermentation of carbohydrates in algae by the bacterium *Pseudomonas elodea*. This fermented carbohydrate is purified with isopropyl alcohol, then dried and milled to produce a powder.

Gellan gum is used as a stabilizer, emulsifier, thickener, and gelling agent in cooking. Aspics and terrines are only some of the dishes that use gellan. It comes in both high-acyl and low-acyl forms. High-acyl gellan gum produces a flexible elastic gel, while low-acyl gellan gum will give way to a more brittle gel.

Like many other hydrocolloids, gellan gum is used with liquids. The powder is normally dispersed in the chosen liquid to dissolve it. Once dissolved, the solution is then heated to facilitate liquid absorption and gelling by the hydrocolloid. A temperature between 85°C and 95°C (185°F and 203°F) will start the dissolution process. Gelling will begin upon cooling around 10°C and 80°C (50°F and 176°F).

Gellan gum creates a thermo-irreversible gel and can withstand high heat without reversing in form. This makes it ideal for the creation of warm gels.

Guar gum

Guar gum, or guaran, is a carbohydrate. This galactomannan is taken from the seeds of the guar plant by dehusking, milling, and screening. The end product is a pale, off-white, loose powder. It is most commonly used as a thickening agent and stabilizer for sauces and dressings in the food industry. Baked goods such as bread may also use guar gum to increase the amount of soluble fibre. At the same time, it also aids with moisture retention in bread and other baked items.

Being a derivative of a legume, guar gum is considered to be vegan and a good alternative to starches. In modern cuisine, guar gum is used for the creation of foams from acidic liquids, for fluid gels, and for stabilizing foams.

Guar gum must first be dissolved in cold liquid. The higher the percentage of guar gum used, the more viscous the liquid will become. Dosage may also vary according to the ingredients used as well as desired results and temperature.

Iota carrageenan

Iota carrageenan is a hydrocolloid taken from red seaweed (*Eucheuma denticulatum)*. It is one of three varieties of carrageenan and is used mainly as a thickening or gelling agent.

Gels produced from iota carrageenan are soft and flexible, especially when used with calcium salts. It produces a clear gel that exhibits little syneresis. Iota is a fast-setting gel that is thermo-reversible and remains stable through freezing and thawing. In modern cuisine it is used to create hot foams as well as custards and jellies with a creamy texture.

Like most other hydrocolloids, iota carrageenan must first be dispersed and hydrated in liquid before use. Unlike lambda carrageenan, it is best dispersed in cold liquid. Once hydrated, the solution must be heated to about 70°C (158°F) with shear to facilitate dissolution. Gelling will happen between 40°C and 70°C (104°F and 158°F) depending on the number of calcium ions present.

Kappa carrageenan

Kappa carrageenan is another type of red seaweed extract taken specifically from *Kappaphycus alvarezii*. Like other types of carrageenan, it is used as a gelling, thickening, and stabilizing agent. When mixed with water, kappa carrageenan creates a strong and firm solid gel that may be brittle in texture.

This particular variety of carrageenan blends well with milk and other dairy products. Since it is taken from seaweed, it is considered to be vegan and is an alternative to traditional gelling agents such as gelatin.

Kappa carrageenan is used in various cooking preparations including hot and cold gels, jelly toppings, cakes, breads, and pastries. When used in molecular gastronomy preparations and other dishes, kappa carrageenan should be dissolved in cold liquid.

Once dispersed, the solution must be heated between 40°C and 70°C (104°F and 158°F). Gelling will begin between 30°C and 60°C (86°F and 140°F). Kappa carrageenan is a thermo-reversible gel and will stay stable up to 70°C (158°F). Temperatures beyond this will cause the gel to melt and become liquid once again.

Locust bean gum

Locust bean gum, also known as LBG and carob bean gum, is a vegetable gum derived from Mediterranean-region carob tree seeds. This hydrocolloid is used to stabilize, texturize, thicken, and gel liquids in modern cuisine, although it has been a popular thickener and stabilizer for many years.

It has a neutral taste that does not affect the flavour of food that it is combined with. It also provides a creamy mouth feel and has reduced syneresis when used alongside pectin or carrageenan for dairy and fruit applications. The neutral behaviour of this hydrocolloid makes it ideal for use with a wide range of ingredients.

To use locust bean gum, it must be dissolved in liquid. It is soluble with both hot and cold liquids.

Maltodextrin

Maltodextrin is a sweet polysaccharide that is produced from starch, corn, wheat, tapioca, or potato through partial hydrolysis and spray drying. This modified food starch is a white powder that has the capacity to absorb and hold water as well as oil. It is an ideal additive since it has fewer calories than sugar and is easily absorbed and digested by the body in the form of glucose.

Coming from a natural source, it ranges from nearly flavourless to fairly sweet without any odour. Maltodextrin is a common ingredient in processed foods such as soda and candies. In molecular gastronomy, it can be used both as a thickener and a stabilizer for sauces and dressings, for encapsulation, and as a sweetener. In many cases, it is also used as an aroma carrier due to its capacity to absorb oil. It is also often used to make powders or pastes out of fat.

Sodium alginate

Sodium alginate, which is also called algin, is a natural gelling agent taken from the cell walls of certain brown seaweed species. This salt is obtained by drying the seaweed, followed by cleaning, boiling, gelling, and pulverizing it. A light yellow powder is produced from the process. When dissolved in liquids, sodium alginate acts as a thickener, creating a viscous fluid. Conversely, when it is used with calcium it forms a gel through a cold process.

In molecular gastronomy, sodium alginate is most commonly used as a texturizing agent. Foams and sauces may be created with it. It is also used in spherification for the creation of pearls, raviolis, mock caviar, marbles, and spheres. Sodium alginate can be used directly by dissolving it into the liquid that needs to be gelled, as in the case of basic spherification. It may also be used inversely by adding it directly to a bath, as in the case of reverse spherification.

This versatile product is soluble in both hot and cold liquids, and gels made with it will set at any temperature.

Soy lecithin

Soy lecithin, also called just lecithin, is a natural emulsifier that comes from fatty substances found in plant tissues. It is derived from soybeans either mechanically or chemically, and is a by-product of soybean oil creation. The end product is a light brown powder that has low water solubility.

As an emulsifier, it works to blend immiscible ingredients together, such as oil and water, giving way to stable preparations. It can be whisked directly into the liquid of choice.

Soy lecithin is also used in creating foams, airs, mousses, and other aerated dishes that are long lasting and full of flavour. It is used in pastries, confections, and chocolate to enhance dough and increase moisture tolerance.

As with most ingredients, dosage and concentration for soy lecithin will depend on the ingredients used, specific properties desired in the resulting preparation, as well as other conditions.

Tapioca maltodextrin

Tapioca maltodextrin is a form of maltodextrin made from tapioca starch. It is a common ingredient in molecular gastronomy because it can be used both as a thickener and stabilizer for sauces and dressings, for encapsulation, and as a sweetener. In many cases it is also used as an aroma carrier due to its capacity to absorb oil. It is often used to make powders or pastes out of fat.

Xanthan gum

Xanthan gum is a food additive used as a thickening agent. It is produced through the fermentation of glucose. As a gluten-free additive it can be used as a substitute in cooking and baking.

As a thickener, when used in low dosages, xanthan gum produces a weak gel with high viscosity that is shear reversible with a high pourability. It also displays excellent stabilizing abilities that allow for particle suspension.

Moreover, xanthan gum mixes well with other flavours without masking them and provides an improved mouth feel to preparations. The presence of bubbles within the thickened liquids often makes way for light and creamy textures. It is used in the production of emulsions, suspensions, raviolis, and foams.

Being a hydrocolloid, xanthan gum must be hydrated before use. High versatility allows it to be dissolved over a wide range of temperatures, acid, and alcohol levels. Once set, xanthan gum may lose some of its effectiveness when exposed to heat.
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21

Sauces

Sauces enhance desserts by both their flavor and their appearance, just as savory sauces enhance meats, fish, and vegetables. Crème anglaise, chocolate sauce, caramel sauce, and the many fruit sauces and coulis are the most versatile. One or another of these sauces will complement nearly every dessert.

Examples of dessert sauces

Caramel sauce: A proper caramel flavor is a delicate balance between sweetness and bitterness. As sugar cooks and begins to change color, a flavor change will occur. The darker the sugar, the more bitter it will become. Depending on the application for the finished caramel, it can be made mild or strong. At this point, a liquid is added. This liquid will serve several roles: it will stop the cooking process, it can add richness and flavor, and it will soften the sauce. The fluidity of the finished sauce will depend on the amount of liquid added to it, and the temperature it is served at. Dairy products, such as cream, milk, or butter, will add richness; use water for a clear sauce; use fruit purées to add different flavor elements.

Chocolate sauce: Sometimes called fudge sauce, chocolate sauce is generally made from cream (or milk), butter, and chocolate, and can be served hot or cold. The proportion of each of the ingredients will affect the thickness of the final product.

Compote: French for “mixture,” a **compote** is cooked fruit served in its own cooking liquid, usually a sugar syrup. Compotes can be made with fresh, frozen, or dried fruits, and served hot or cold.

Coulis: French for “strained liquid,” a **coulis** is most often an uncooked, strained purée. Flavors remain pure, and the colors bright. One of the drawbacks of using a coulis is that it may separate quickly when used as a plating sauce. It’s best to use à la minute.

Crème anglaise: French for “English custard,” **crème anglaise** is a rich, pourable custard sauce that can be served hot or cold over cake, fruits, or other desserts. Made with eggs, sugar, and milk or cream, it is stirred over heat until it thickens into a light sauce. However, it’s a delicate operation: too much heat turns it into scrambled eggs! It should not get above 85°C (185°F) during the cooking process. Vanilla is the classic flavoring, but coffee, spices, chocolate, or liqueurs can be added. With additional yolks and heavy cream, it becomes the “custard” used for French ice cream. With additional yolks, gelatin, whipped cream, and flavoring, it becomes Bavarian cream.

Curd: A **curd** is creamy and fruit based, with citrus and berry flavors being the most popular. Made from fruit juices, eggs, butter, and sugar cooked in a process similar to crème anglaise, curds can be thick, pourable sauces or spreads.

Fruit butter: Fruit butter is a spread made from whole fruits, cooked, reduced, and puréed (if you don’t want any chunks in it) until very thick. It does not contain any butter; the term refers to the consistency.

Fruit sauce: A fruit sauce is a fruit purée, cooked and thickened with a starch. It is normally served cold.

Hard sauce: This traditional sauce for Christmas pudding, or any steamed pudding, is made by combining butter, sugar, and flavorings, often liqueurs. It is normally piped into shapes and chilled, then placed on the warm dessert just before serving.

Sabayon: Sabayon is a mixture of egg yolks, flavoring, and sugar beaten over simmering water until thick, then beaten until cool. It is traditionally flavored with sweet white wine or liquor, then served over fresh fruit and grilled (when it is called a gratin). The Italian version of this is called a **zabaglione** and is flavored with Madeira wine.

Whipped cream: This very popular dessert topping can be served plain, sweetened, or flavored. **Crème chantilly**, a classic version of this, is a combination of whipped cream, sugar, and vanilla.

Applying dessert sauces

Except in the case of some home-style or frozen desserts, sauces are usually not ladled over the dessert because doing so would mar the appearance. Instead, the sauce is applied in a decorative fashion to the plate rather than the dessert. Many different styles of plate saucing are available.

Pouring a pool of sauce onto the plate is known as *flooding*. Although plate flooding often looks old-fashioned today, it can still be a useful technique for many desserts. Flooded plates can be made more attractive by applying a contrasting sauce and then blending or feathering the two sauces decoratively with a pick or the end of a knife. For this technique to work, the two sauces should be at about the same fluidity or consistency.

Rather than flooding the entire plate, it may be more appropriate for some desserts to apply a smaller pool of sauce to the plate, as this avoids overwhelming the dessert with too much sauce.

A variation of the flooding technique is outlining, where a design is piped onto the plate with chocolate and allowed to set. The spaces can then be flooded with colorful sauces.

A squeeze bottle is useful for making dots, lines, curves, and streaks of sauce in many patterns. Or just a spoon is needed to drizzle random patterns of sauce onto a plate. Another technique for saucing is applying a small amount of sauce and streaking it with a brush, an offset spatula, or the back of a spoon.

Sauces are a great way to highlight flavors. Choose ones that will create balance on the plate, not just for color, but with all the components. A tart berry sauce will complement a rich cheesecake or chocolate dessert because sourness (acid) will cut through fat, making it taste lighter than it is. A sweet sauce served with a sweet dessert will have the overall effect of hiding flavors in both. Hold back on sweetness in order to intensify other flavors.

Many modern presentations may have a minimal amount of sauce. Sometimes this is done just for aesthetic reasons and not for how it will complement the dessert. Think of the dish and the balance of the components. This is the most important factor: flavor first, presentation second.
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22

Low-temperature and sous-vide

Sous-vide cooking is about immersing a food item in a precisely controlled water bath, where the temperature of the water is the same as the target temperature of the food being cooked. Food is placed in a food-grade plastic bag and vacuum-sealed before going into the water bath. Temperatures will vary depending on desired end result. This allows the water in the bath to transfer heat into the food while preventing the water from coming into direct contact with it. This means the water does not chemically interact with the food: the flavors of the food remain stronger, because the water is unable to dissolve or carry away any compounds in the food (Figure 1).

Figure 1. *"Img_0081" by Derek is licensed under CC BY-SA-ND 2.0*

Sous-vide fruits and vegetables

Cooking vegetable and fruits sous-vide is a great way to tenderize them without losing as many of the vitamins and minerals that are normally lost through blanching or steaming. Fruits can also be infused with liquid when cooked at lower temperatures by adding liquid to the bag. Sous-vide helps preserve the nutrients present in fruits and vegetables by not cooking them above the temperatures that cause the cell walls to fully break down. This allows them to tenderize without losing all their structure. The bag also helps to catch any nutrients that do come out of the vegetable.

While time and temperature do not factor into safety for fruits and vegetables, they do have a unique effect on their structure. There are two components in fruits and vegetables that make them crisp: pectin and starch. Pectin, which is a gelling agent commonly used in jams and jellies for structure, breaks down at 83ºC (183ºF) at a slower rate than the starch cells do. In many cases this allows for more tender fruits and vegetables that have a unique texture to them.

Custards

The term *custard* spans so many possible ingredients and techniques that it is most useful to think of a custard as simply a particular texture and mouth feel. Custards have been made for centuries by lightly cooking a blend of eggs, milk, and heavy cream, but modernist chefs have invented myriad ways to make custards.

Using the sous-vide method to prepare crème anglaise, curds, ice cream bases, custard bases, sabayons, and dulce de leche is possible. The technique offers greater consistency and more control over the texture, which can range from airy, typical of a sabayon, to dense, as in a posset. For custards, eggs will be properly cooked at 82°C (180ºF), so if the water bath is set to this temperature, no overcooking can happen. The one constant among custards is the use of plenty of fat, which not only provides that distinctive mouth feel but also makes custard an excellent carrier of fat-soluble flavors and aromas. Lighter varieties of custard, prepared sous-vide style and cooled, can be aerated in a whipping siphon into smooth, creamy foams.

Other applications for vacuum-seal processes

Fruit compression

Vacuum-compressing fruits and vegetables is a popular modern technique that can give many plant foods an attractive, translucent appearance (as shown in the watermelon in Figure 2) and a pleasant, surprising texture. This technique exploits the ability of a vacuum chamber to reduce surrounding pressure, which causes air and moisture within the plant tissue to rapidly expand and rupture the structures within the food. When the surrounding pressure is restored to a normal level, the labyrinth of air-filled spaces collapses. As a result, light tends to pass through the food rather than being scattered and diffused, which is why vacuum-compressed plant foods appear translucent. Causing the porous structure of a plant food to collapse also imparts a somewhat dense, toothsome texture that can give a familiar ingredient, such as watermelon, an entirely new appeal.

Figure 5. *"WD-50 (7th Course)" by Peter Dillon is licensed under CC BY 2.0*

Infusions

When adding liquids, the vacuum-seal process creates a rapid infusion—especially with more porous foods (such as adding spices to cream or herbs to melon). This can add flavor and texture in a shorter time than traditional infusions.
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Understanding Ingredients: Flour

23

Introduction -- Understanding Ingredients

Ingredients play an important role in baking. Not only do they provide the structure and flavour of all of the products produced in the bakery or pastry shop, their composition and how they react and behave in relation to each other are critical factors in understanding the science of baking. This is perhaps most evident when it comes to adapting formulas and recipes to accommodate additional or replacement ingredients while still seeking a similar outcome to the original recipe.

In this book, we look at each of the main categories of baking ingredients, listed below, and then explore their composition and role in the baking process. In addition to these categories, we will discuss the role that salt and water play in the baking process.

The main categories of baking ingredients are:

- Grains and flours
- Sweeteners
- Fats oils
- Leavening agents
- Eggs
- Dairy products
- Chocolate and other cocoa products
- Nuts and seeds
- Thickening agents
- Spices and other flavourings
- Fruit

Note: For most measurements used in the open textbook series, both S.I. (metric) and U.S./imperial values are given. The exception is nutritional information, which is always portrayed using metric values in both Canada and the United States.
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24

The History of Wheat Flour

Archaeologists who did excavations in the region of the lake dwellers of Switzerland found grains of wheat, millet, and rye 10,000 years old. The Romans perfected the rotary mill for turning wheat into flour. By the time of Christ, Rome had more than 300 bakeries, and Roman legions introduced wheat throughout their empire. Improved milling processes were needed because even when wheat was milled twice and bolted (sifted) through silk gauze, the result was still a yellowish flour of uneven texture and flecked with germ and bran.

In the second half of the 19th century, there were great changes in the flour milling process. An American inventor, Edmund LaCroix, improved the process with a purifier to separate the **middlings** (bran, germ, and other coarse particles) from the particles that form smooth-textured white flour. In recent years, the demand for whole grain milling has increased because whole grain food products have proved to be more nutritious than products made from white flour. (More information on whole grain and artisan milling is provided later in this section.)

In Canada, large-scale wheat growing didn't occur until after the Prairies were settled in the 1800s. Hard wheat, such as Red Fife, Marquis, and Selkirk, earned Canada a position as the granary for Britain and many other European countries. Today, most of the wheat grown in Western Canada is the hard Red Spring variety. Soft wheats, such as soft red and soft white, are primarily grown in Quebec and Ontario. Many of the original wheat growers have passed on their farms to the next generations, while others branched out to organic farming and milling. One of these farms, Nunweiler's, has a heritage that goes back to the early 1900s when the original wheat in Canada, Red Fife and Marquis, was grown on this farm.

Today, the major wheat growing areas of North America are in the central part of the continent, in the Great Plains of the United States and the Canadian Prairies. From Nebraska south, winter wheat can be grown, while to the north through Saskatchewan spring wheat dominates. Many American states and some Canadian provinces grow both kinds. In fact, there are very few states that don't grow some wheat. Kansas, the site of the American Institute of Baking, could be said to be at the heart of the U.S. wheat growing area, while Saskatchewan is the Canadian counterpart.

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25

Milling of Wheat

Milling of wheat is the process that turns whole grains into flours. The overall aims of the miller are to produce:

- A consistent product
- A range of flours suitable for a variety of functions
- Flours with predictable performance

The very first mill operation is analyzing the grain, which determines criteria such as the **gluten** content and amylase activity. It is at this point that decisions about blending are made.

Following analysis, milling may be divided into three stages:

Cleaning and conditioning – ridding the grain of all impurities and readying it for milling
Crushing or breaking – breaking down the grain in successive stages to release its component parts
Reduction – progressive rollings and siftings to refine the flour and separate it into various categories, called *streams*

Cleaning

Wheat received at the mill contains weeds, seeds, chaff, and other foreign material. Strong drafts of air from the aspirator remove lighter impurities. The **disc separator** removes barley, oats, and other foreign materials. From there, the wheat goes to the scourers in which it is driven vigorously against perforated steel casings by metal beaters. In this way, much of the dirt lodged in the crease of the wheat berry is removed and carried away by a strong blast of air. Then the magnetic separator removes any iron or steel.

At this point, the wheat is moistened. Machines known as *whizzers* take off the surface moisture. The wheat is then **tempered**, or allowed to lie in bins for a short time while still damp, to toughen the bran coat, thus making possible a complete separation of the bran from the flour-producing portion of the wheat berry. After tempering, the wheat is warmed to a uniform temperature before the crushing process starts.

Crushing or Breaking

The objectives at this stage are twofold:

Separate as much bran and germ as possible from the endosperm
Maximize the flour from the resulting endosperm

Household grain mills create flour in one step — grain in one end, flour out the other — but the commercial mill breaks the grain down in a succession of very gradual steps, ensuring that little bran and germ are mixed with any endosperm.

Although the process is referred to as *crushing*, flour mills crack rather than crush the wheat with large steel rollers. The rollers at the beginning of the milling system are corrugated and break the wheat into coarse particles. The grain passes through screens of increasing fineness. Air currents draw off impurities from the **middlings**. *Middlings* is the name given to coarse fragments of endosperm, somewhere between the size of semolina and flour. Middlings occur after the “break” of the grain.

Bran and germ are sifted out, and the coarse particles are rolled, sifted, and purified again. This separation of germ and bran from the endosperm is an important goal of the miller. It is done to improve dough-making characteristics and colour. As well, the germ contains oil and can affect keeping qualities of the flour.

Reduction

In the reduction stage, the coarser particles go through a series of fine rollers and sieves. After the first crushing, the wheat is separated into five or six streams. This is accomplished by means of machines called **plansifters** that contain sieves, stacked vertically, with meshes of various sizes. The finest mesh is as fine as the finished flour, and some flour is created at an early stage of reduction.

Next, each of the divisions or streams passes through cleaning machines, known as *purifiers*, a series of sieves arranged horizontally and slightly angled. An upcurrent draught of air assists in eliminating dust. The product is crushed a little more, and each of the resulting streams is again divided into numerous portions by means of sifting. The final crushings are made by perfectly smooth steel rollers that reduce the middlings into flour. The flour is then bleached and put into bulk storage. From bulk storage, the flour is **enriched** (thiamine, niacin, riboflavin, and iron are added), and either bagged for home and bakery use or made ready for bulk delivery.

Extraction Rates

The extraction rate is a figure representing the percentage of flour produced from a given quantity of grain. For example, if 82 kg of flour is produced from 100 kg of grain, the extraction rate is 82% (82÷100×100). Extraction rates vary depending on the type of flour produced. A whole grain flour, which contains all of the germ, bran, and endosperm, can have an extraction rate of close to 100%, while white all-purpose flours generally have extraction rates of around 70%. Since many of the nutrients are found in the germ and bran, flours with a higher extraction rate have a higher nutritional value.
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26

Flour Streams and Types of Wheat Flour

Modern milling procedures produce many different **flour streams** (approximately 25) that vary in quality and chemical analysis. These are combined into four basic streams of edible flour, with four other streams going to feed.

- Top patent flour: This stream is composed of only the purest and most highly refined streams from the mill. It is low in ash and is approximately 50% of the flour extracted. The term *ash* indicates the mineral content (e.g., phosphorus) of the flour. When flour is burned, all that is left is the burned mineral elements that constitute ash.
- Second patent flour: This flour is composed of streams with an intermediate degree of refinement. It has an average ash content of approximately 0.45% and represents about 35% of the total flour.
- First clear flour: This stream contains the balance of the flour that possesses baking properties, and is high in ash and protein content. It is usually about 15% of the total flour.
- Second clear flour: This grade contains the poorest flour streams. It is very high in ash (approximately 0.75%), and has little or no baking quality. It is about 2% of the total flour.
- Feed streams: The balance of the streams from the mill are classed as feed. Feeds are marketed as bran, **wheat shorts**, flour middlings, and wheat germ.

Within the streams of edible flours, there are a number of different types of flour used in food preparation. Each has different characteristics, and with those come different uses, as described below.

All-Purpose Flour

General purpose or home use flours are usually a blend of hard spring wheats that are lower in protein (gluten) content than bread flours. They are top patent flours and contain sufficient protein to make good yeast breads, yet not too much for good quick breads, cakes, and cookies.

Note: A word about gluten quality as opposed to gluten quantity: The fact that a particular flour contains a high quantity of protein, say 13% to 15%, does not necessarily mean that it is of high quality. It may contain too much ash or too much damaged starch to warrant this classification. High quality is more important in many bread applications than high quantity. All-purpose flour is an example of a high-quality flour, with a protein content of about 12%.

Graham Flour

A U.S. patented flour, graham flour is a combination of whole wheat flour (slightly coarser), with added bran and other constituents of the wheat kernel.

Bread Flour

Bread flour is milled from blends of hard spring and hard winter wheats. They average about 13% protein and are slightly granular to the touch. This type of flour is sold chiefly to bakers because it makes excellent bread with bakery equipment, but has too much protein for home use. It is also called strong flour or hard flour and is second patent flour.

For example, the specification sheet on bread flour produced by a Canadian miller might include the following information:

Ingredients: Wheat flour, amylase, ascorbic acid, niacin, iron, thiamine mononitrate, riboflavin, azodicarbonamide, folic acid.

Moisture: 14.2%

Ash: 0.54%

Protein (5.7 x N) 13.00%

Along with this information there is microbiological data and an allergen declaration. (Note that the formula in parentheses beside "Protein" is simply the laboratory's way of deriving the protein figure from the nitrogen content.)

Cake Flour

Cake flour is milled from soft winter wheats. The protein content is about 7% and the granulation is so uniform and fine that the flour feels satiny. An exception is a high-protein cake flour formulated especially for fruited pound cakes (to prevent the fruit from sinking).

Clear Flour

Clear flour comes from the part of the wheat berry just under the outer covering. Comparing it to first patent flour is like comparing cream to skim milk. It is dark in colour and has a very high gluten content. It is used in rye and other breads requiring extra strength.

Gluten Flour

Gluten flour is made from wheat flour by removing a large part of the starch. It contains no more than 10% moisture and no more than 44% starch.

Pastry Flour

Pastry flour is made from either hard or soft wheat, but more often from soft. It is fairly low in protein and is finely milled, but not so fine as cake flour. It is unsuitable for yeast breads but ideal for cakes, pastries, cookies, and quick breads.

Self-Rising Flour

Self-rising flour has leavening and salt added to it in controlled amounts at the mill.

Wheat Germ Flour

Wheat germ flour consists entirely of the little germ or embryo part of the wheat separated from the rest of the kernel and flattened into flakes. This flour should be refrigerated.

Whole Wheat Flour

Whole wheat flour contains all the natural parts of the wheat kernel up to 95% of the total weight of the wheat. It contains more protein than all-purpose flour and produces heavier products because of the bran particles.

Whole Wheat Pastry Flour

Whole wheat pastry flour is milled from the entire kernel of soft wheat, is low in gluten, and is suitable for pastry, cakes, and cookies.

Hovis Flour

Most of the germ goes away with the shorts and only a small fraction of the total quantity can be recovered in a fairly pure form. At the mill, a special process developed in England to improve its keeping qualities and flavour cooks this fraction. It is then combined with white flour to make Hovis flour, which produces a loaf that, though small for its weight, has a rich, distinctive flavour.

Triticale Flour

The world's first new grain, triticale is a hybrid of wheat and rye. It combines the best qualities of both grains. It is now grown commercially in Manitoba.

Semolina

Semolina is the granular product consisting of small fragments of the endosperm of the durum wheat kernel. (The equivalent particles from other hard wheat are called *farina*.) The commonest form of semolina available commercially is the breakfast cereal Cream of Wheat.

No-Time Flour

The primary goal of all bakers has been to reduce production time and keep costs to a minimum without losing quality, flavour, or structure. After extensive research, millers have succeeded in eliminating bulk fermentation for both sponge and straight dough methods. No-time flour is flour with additives such as ascorbic acid, bromate, and cysteine. It saves the baker time and labour, and reduces floor space requirements. The baker can use his or her own formulas with only minor adjustments.

Blending Flours

Blending of flours is done at the mill, and such is the sophistication of the analysis and testing of flours (test baking, etc.) that when problems occur it is generally the fault of the baker and not the product. Today the millers and their chemists ensure that bakers receive the high grade of flour that they need to produce marketable products for a quality-conscious consumer. Due to the vagaries of the weather and its effect on growing conditions, the quality of the grain that comes into the mill is hardly ever constant. For example, if damp weather occurs at harvest time, the grain may start to sprout and will cause what is known as *damaged starch*. Through analysis and adjustments in grain handling and blending, the miller is able to furnish a fairly constant product.

Bakers do blend flours, however. A portion of soft flour may be blended with the bread flour to reduce the toughness of a Danish pastry or sweet dough, for example. Gluten flour is commonly used in multigrain bread to boost the aeration.
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27

Flour Terms and Treatments

In addition to types of flour, you may come across various other terms when purchasing flour. These include some terms that refer to the processing and treatment of the flour, and others outlining some of the additives that may be added during the milling and refining process.

Bleached

Bleaching and maturing agents are added to whiten and improve the baking quality quickly, making it possible to market the freshest flour. Even fine wheat flours vary in colour from yellow to cream when freshly milled. At this stage, the flour produces doughs that are usually sticky and do not handle well. Flour improves with age under proper storage conditions up to one year, both in colour and quality.

Because storing flour is expensive, toward the close of the 19th century, millers began to treat freshly milled flour with oxidizing agents to bleach it and give it the handling characteristics of naturally aged flour. Under the category of maturing agents are included materials such as chlorine dioxide, chlorine gas plus a small amount of nitrosyl chloride, ammonium persulfate, and ascorbic acid. No change occurs in the nutritional value of the flour when these agents are present.

There are two classes of material used to bleach flour. A common one, an organic peroxide, reacts with the yellow pigment only, and has no effect on gluten quality. Chlorine dioxide, the most widely used agent in North America, neutralizes the yellow pigment and improves the gluten quality. It does, however, destroy the tocopherols (vitamin E complex).

Enriched

Iron and three of the most necessary B vitamins (thiamin, riboflavin, and niacin), which are partially removed during milling, are returned to white flour by a process known as enrichment. No change occurs in taste, colour, texture, baking quality, or caloric value of the flour.

Pre-sifted

During the milling process, flour is sifted many times through micro-fine silk. This procedure is known as pre-sifting. The mesh size used for sifting varies from flour to flour. There are more holes per square inch for cake flour than, for example, bread flour, so that a cup of cake flour has significantly more minute particles than does a cup of bread flour, is liable to be denser, and weigh slightly more. Sifted flour yields more volume in baked bread than does unsifted flour, simply because of the increased volume of air.

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28

Flour Additives

A number of additives may be found in commercial flours, from agents used as dough conditioners, to others that aid in the fermentation process. Why use so many additives? Many of these products are complementary – that is, they work more effectively together and the end product is as close to "ideal" as possible. Nevertheless, in some countries the number of additives allowed in flour are limited. For instance, in Germany, ascorbic acid remains the only permitted additive.

Some of the additives that are commonly added to flour include those described below.

Bromate

Until the early 1990s, bromate was added to flour because it greatly sped up the oxidation or aging of flour. Millers in Canada stopped using it after health concerns raised by the U.S. Food and Drug Administration (FDA). In the United States, bromate is allowed in some states but banned in others (e.g., California).

Azodicarbonamide (ADA)

Approved in the United States since 1962, but banned in Europe, ADA falls under the food additives permitted in Canada. ADA is a fast-acting flour treatment resulting in a cohesive, dry dough that tolerates high water absorption. It is not a bleach, but because it helps produce bread with a finer texture it gives an apparently whiter crumb. It does not destroy any vitamins in the dough.

Bakers who want to know if their flours contain ADA or other chemical additives can request this information from their flour suppliers.

L-Cysteine

An amino acid, L-cysteine speeds up reactions within the dough, thus reducing or almost eliminating bulk fermentation time. In effect, it gives the baker a "no-time" dough. It improves dough elasticity and gas retention.

Ascorbic Acid

Ascorbic acid was first used as a bread improver in 1932, after it was noticed that old lemon juice added to dough gave better results because it improved gas retention and loaf volume. Essentially vitamin C (ascorbic acid) has the advantage of being safe even if too much is added to the dough, as the heat of baking destroys the vitamin component. The addition of ascorbic acid consistent with artisan bread requirements is now routine for certain flours milled in North America.

Calcium Peroxide

Calcium peroxide (not to be confused with the peroxide used for bleaching flour) is another dough-maturing agent.

Glycerides

Glycerides are multi-purpose additives used in both cake mixes and yeast doughs. They are also known as surfactants, which is a contraction for "surface-acting agents." In bread doughs, the main function of glycerides is as a crumb-softening agent, thus retarding bread staling. Glycerides also have some dough-strengthening properties.

Sodium Stearoyl Lactylate

Approved for use in the United States since 1961, this additive improves gas retention, shortens proofing time, increases loaf volume, and works as an anti-staling agent.
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29

Whole Grain and Artisan Milling

Whole grain and artisan milling is the type of milling that was practiced before the consumer market demanded smooth white flours that are refined and have chemical additives to expedite aging of flours. Artisan milling produces flours that are less refined and better suited to traditional breads, but also contain little to no additives and have higher nutritional content. For that reason, demand for these types of flour is on the rise.

Artisan millers (also known as micro millers) process many non-stream grains, including spelt, kamut, buckwheat, and other non-gluten grains and pulses. This offers bakers opportunities to work with different grains and expand their businesses. Artisan flours are readily available directly from millers or through a distributor. Knowing the origin of the grains and the quality of the ingredients in baking is important for artisan bakers.

Whole grain flours are on the increase as consumers become more aware of their benefits. Whole grain flour, as the name suggests, is made from whole grains.

Many artisan millers purchase their grains directly from growers. This method of purchasing establishes trustworthy working relationships with the grain growers and promotes transparency in grain growing and food safety practices. Grain growers that sell their grains to artisan millers apply conventional or organic growing practices. Grain growers and millers have to go through vigorous processes to obtain the **certified organic** certification for their grains or products, which guarantees that no chemical additives have been used.

How organic grain is processed varies. Stone milling and impact hammer milling methods are typical when minimal refined whole grain flour is preferred. Information on several American artisan millers that produce various whole grain flours can be found at Firebid Mills; Hayden Flour Mills; and Baker Miller Chicago. Organic flours have gained popularity in the baking industry. As consumers become more aware of them, we see the demand swinging back toward whole grain and artisan milling as a preference.
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30

Flour in Baking

Flour forms the foundation for bread, cakes, and pastries. It may be described as the skeleton, which supports the other ingredients in a baked product. This applies to both yeast and chemically leavened products.

The strength of flour is represented in protein (gluten) quality and quantity. This varies greatly from flour to flour. The quality of the protein indicates the strength and stability of the flour, and the result in bread making depends on the method used to develop the gluten by proper handling during the fermentation. Gluten is a rubber-like substance that is formed by mixing flour with water. Before it is mixed it contains two proteins. In wheat, these two proteins are **gliadin** and **glutenin**. Although we use the terms *protein* and *gluten* interchangeably, gluten only develops once the flour is moistened and mixed. The protein in the flour becomes gluten.

Hard spring wheat flours are considered the best for bread making as they have a larger percentage of good quality gluten than soft wheat flours. It is not an uncommon practice for mills to blend hard spring wheat with hard winter wheat for the purpose of producing flour that combines the qualities of both. Good bread flour should have about 13% gluten.

Storing Flour

Flour should be kept in a dry, well-ventilated storeroom at a fairly uniform temperature. A temperature of about 21°C (70°F) with a relative humidity of 60% is considered ideal. Flour should never be stored in a damp place. Moist storerooms with temperatures greater than 23°C (74°F) are conducive to mould growth, bacterial development, and rapid deterioration of the flour. A well-ventilated storage room is necessary because flour absorbs and retains odors. For this reason, flour should not be stored in the same place as onions, garlic, coffee, or cheese, all of which give off strong odors.

Flour Tests

Wheat that is milled and blended with modern milling methods produce flours that have a fairly uniform quality all year round and, if purchased from a reliable mill, they should not require any testing for quality. The teacher, student, and professional baker, however, should be familiar with qualitative differences in flours and should know the most common testing methods.

Flours are mainly tested for:

- Color
- Absorption
- Gluten strength
- Baking quality

Other tests, done in a laboratory, are done for:

- Albumen
- Starch
- Sugar
- Dextrin
- Mineral and fat content

Color

The color of the flour has a direct bearing on baked bread, providing that fermentation has been carried out properly. The addition of other ingredients to the dough, such as **brown sugar**, malt, molasses, salt, and colored margarine, also affects the color of bread.

To test the color of the flour, place a small quantity on a smooth glass, and with a spatula, work until a firm smooth mass about 5 cm (2 in.) square is formed. The thickness should be about 2 cm (4/5 in.) at the back of the plate to a thin film at the front. The test should be made in comparison with a flour of known grade and quality, both flours being worked side by side on the same glass. A creamy white color indicates a hard flour of good gluten quality. A dark or greyish color indicates a poor grade of flour or the presence of dirt. Bran specks indicate a low grade of flour.

After making a color comparison of the dry samples, dip the glass on an angle into clean water and allow to partially dry. Variations in color and the presence of bran specks are more easily identified in the damp samples.

Absorption

Flours are tested for absorption because different flours absorb different amounts of water and therefore make doughs of different consistencies. The absorption ability of a flour is usually between 55% and 65%. To determine the absorption factor, place a small quantity of flour (100 g/4 oz.) in a bowl. Add water gradually from a beaker containing a known amount of water. As the water is added, mix with a spoon until the dough reaches the desired consistency. You can knead the dough by hand for final mixing and determination of consistency. Weigh the unused water. Divide the weight of the water used by the weight of the flour used. The result is the absorption ability in percentage. For example:

Weight of flour used 100 g (4 oz.)

Weight of water used 60 g (2.7 oz.)

Therefore absorption = 6/10 or 60%

Prolonged storage in a dry place results in a natural moisture loss in flour and has a noticeable effect on the dough. For example, a sack of flour that originally weighed 40 kg (88 lb.) with a moisture content of 14% may be reduced to 39 kg (86 lb.) during storage. This means that 1 kg (2 lb.) of water is lost and must be made up when mixing. The moisture content of the wheat used to make the flour is also important from an economic standpoint.

Hard wheat flour absorbs more liquid than soft flour. Good hard wheat flour should feel somewhat granular when rubbed between the thumb and fingers. A soft, smooth feeling indicates a soft wheat flour or a blend of soft and hard wheat flour. Another indicator is that hard wheat flour retains its form when pressed in the hollow of the hand and falls apart readily when touched. Soft wheat flour tends to remain lumped together after pressure.

Gluten Strength

The gluten test is done to find the variation of gluten quality and quantity in different kinds of flour. Hard flour has more gluten of better quality than soft flour. The gluten strength and quality of two different kinds of hard flour may also vary with the weather conditions and the place where the wheat is grown. The difference may be measured exactly by laboratory tests, or roughly assessed by the variation of gluten balls made from different kinds of hard flours.

For example, to test the gluten in hard flour and all-purpose flour, mix 250 g (9 oz.) of each in separate mixing bowls with enough water to make each dough stiff. Mix and develop each dough until smooth. Let the dough rest for about 10 minutes. Wash each dough separately while kneading it under a stream of cold water until the water runs clean and all the starch is washed out. (Keep a flour sieve in the sink to prevent dough pieces from being washed down the drain.) What remains will be crude gluten. Shape the crude gluten into round balls, then place them on a paper-lined baking pan and bake at 215°C (420°F) for about one hour. The gluten ball made from the hard flour will be larger than the one made from all-purpose flour. This illustrates the ability of hard flour to produce a greater volume because of its higher gluten content.

Ash Content

Ash or mineral content of flour is used as another measurement of quality. Earlier in the chapter, we talked about extraction rates as an indicator of how much of the grain has been refined. Ash content refers to the amount of ash that would be left over if you were to burn 100 g of flour. A higher ash content indicates that the flour contains more of the germ, bran, and outer endosperm. Lower ash content means that the flour is more highly refined (i.e., a lower extraction rate).

Baking Quality

The final and conclusive test of any flour is the kind of bread that can be made from it. The baking test enables the baker to check on the completed loaf that can be expected from any given flour. Good volume is related to good quality gluten; poor volume to young or green flour. Flour that lacks stability or power to hold during the entire fermentation may result in small, flat bread. Flour of this type may sometimes respond to an increase in the amount of yeast. More yeast shortens the fermentation time and keeps the dough in better condition during the pan fermentation period.

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31

Rye Flour

Rye is a hardy cereal grass cultivated for its grain. Its use by humans can be traced back over 2,000 years. Once a staple food in Scandinavia and Eastern Europe, rye declined in popularity as wheat became more available through world trade. A crop well suited to northern climates, rye is grown on the Canadian Prairies and in the northern states such as the Dakotas and Wisconsin.

Rye flour is the only flour other than wheat that can be used without blending (with wheat flour) to make yeast-raised breads. Nutritionally, it is a grain comparable in value to wheat. In some cases, for example, its lysine content (an amino acid), is even biologically superior.

The brown grain is cleaned, tempered, and milled much like wheat grain. One difference is that the rye endosperm is soft and breaks down into flour much quicker that wheat. As a result, it does not yield semolina, so purifiers are seldom used. The bran is separated from the flour by the break roller, and the flour is further rolled and sifted while being graded into chop, meal, light flour, medium flour, and dark flour:.

- Chop: This is the miller’s name for the coarse stock after grinding in a break roller mill.
- Meal: Like chop, meal is made of 100% extraction obtained by grinding the entire rye kernel.
- Light rye flour: This is obtained from the centre of the rye kernel and is low in protein and high in starch content. It can be compared to white bread flour and is used to make light rye breads.
- Medium rye flour: This is straight flour and consists of all the kernels after the bran and shorts have been removed. It is light grey in colour, has an ash content of 1%, and is used for a variety of sourdough breads.
- Dark rye flour: This is comparable to first clear wheat flour. It has an ash content of 2% and a protein content of 16%. It is used primarily for heavier types of rye bread.

The lighter rye flours are generally bleached, usually with a chlorine treatment. The purpose of bleaching is to lighten the colour, since there is no improvement on the gluten capability of the flour.

Extraction of Rye Flour

The grade of extraction of rye flour is of great importance to the yield of the dough and the creation of a particular flavour in the baked bread. Table 1 shows the percentage of the dry substances of rye flour by grade of extraction.

Table 1 Table of extraction for rye flour

Substance	**Grade of Extraction**	
	70%	**85%**
Ash	0.8%	1.4%
Fat	1.2%	1.7%
Protein	8.1%	9.6%
Sugar	6.5%	7.5%

Starch	72.5%	65.1%
Crude fibre	0.5%	1.3%
Pentosans	5.2%	7.6%
Undefinable	5.2%	5.8%

Note that ash, fibre, and **pentosans** are higher in the 85% extraction rate flour, and starch is lower. Pentosans are gummy carbohydrates that tend to swell when moistened and, in baking, help to give the rye loaf its cohesiveness and structure. The pentosan level in rye flour is greater than that of wheat flour and is of more significance for successful rye bread baking.

Rye flours differ from wheat flours in the type of gluten that they contain. Although some dark rye flours can have a gluten content as high as 16%, this is only gliadin. The glutenin, which forms the elasticity in dough is absent, and therefore doughs made only with rye flour will not hold the gas produced by the yeast during fermentation. This results in a small and compact loaf of bread.

Starch and pentosans are far more important to the quality of the dough yield than gluten. Starch is the chief component of the flour responsible for the structure of the loaf. Its bread-making ability hinges on the age of the flour and the acidity. While rye flour does not have to be aged as much as wheat flour, it has both a “best after” and a “best before” date. Three weeks after milling is considered to be good.

When the rye flour is freshly milled, the starch gelatinizes (sets) quickly at a temperature at which amylases are still very active. As a result, bread made from fresh flour may be sticky and very moist. At the other extreme, as the starch gets older, it gelatinizes less readily, the enzymes cannot do their work, and the loaf may split and crack. A certain amount of starch breakdown must occur for the dough to be able to swell.

The moisture content of rye flour should be between 13% and 14%. The less water in the flour, the better its storage ability. Rye should be stored under similar conditions to wheat flour.

Differences between Rye and Wheat

Here is a short list of the differences between rye and wheat:

- Rye is more easily pulverized.
- Rye does not yield semolina.
- Gluten content in rye is not a significant dough-making factor.
- Starch is more important for bread making in rye flour than in wheat flour.
- The pentosan level in rye flour is higher and more important for bread making.
- Rye flour has greater water binding capability than wheat flour, due to its starch and pentosan content.

In summary, both wheat and rye have a long history in providing the “staff of life.” They are both highly nutritious. North American mills have state-of-the-art technology that compensates for crop differences, thus ensuring that the baker has a reliable and predictable raw material. Flour comes in a great variety of types, specially formulated so that the baker can choose according to product and customer taste.
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32

Other Grains and Flours

Several other types of grains are commonly used in baking. In particular, corn and oats feature predominantly in certain types of baking (quick breads and cookies respectively, for instance) but increasingly rice flour is being used in baked goods, particularly for people with gluten sensitivities or intolerances. The trend to whole grains and the influence of different ethnic cultures has also meant the increase in the use of other grains and pulses for flours used in breads and baking in general.

Corn

Corn is one of the most widely used grains in the world, and not only for baking. Corn in used in breads and cereals, but also to produce sugars (such as dextrose and corn syrup), starch, plastics, adhesives, fuel (ethanol), and alcohol (bourbon and other whisky). It is produced from the **maize** plant (the preferred scientific and formal name of the plant that we call *corn* in North America). There are different varieties of corn, some of which are soft and sweet (corn you use for eating fresh or for cooking) and some of which are starchy and are generally dried to use for baking, animal feed, and popcorn.

Varieties Used in Baking

- Cornmeal has a sandy texture and is ground to fine, medium, and coarse consistencies. It has most of the husk and germ removed, and is used is recipes from the American South (e.g., cornbread) and can be used to add texture to other types of breads and pastry.
- Stone-ground cornmeal has a texture not unlike whole wheat flour, as it contains some of the husk and germ. Stone ground cornmeal has more **nutrients**, but it is also more perishable. In baking, it acts more like cake flour due to the lack of gluten.
- Corn flour in North America is very finely ground cornmeal that has had the husk and germ removed. It has a very soft powdery texture. In the U.K. and Australia, corn flour refers to cornstarch.
- Cornstarch is the starch extracted from the maize kernel. It is primarily used as a thickener in baking and other cooking. Cornstarch has a very fine powdery consistency, and can be dissolved easily in water. As a thickening agent, it requires heat to set, and will produce products with a shiny, clear consistency.
- Blue cornmeal has a light blue or violet colour and is produced from whole kernels of blue corn. It is most similar to stone-ground cornmeal and has a slightly sweet flavour.

Rice

Rice is another of the world’s most widely used cereal crops and forms the staple for much of the world’s diet. Because rice is not grown in Canada, it is not regulated by the Canadian Grain Commission.

Varieties Used in Baking

- Rice flour is prepared from finely ground rice that has had the husks removed. It has a fine, slightly sandy texture, and provides crispness while remaining tender due to its lack of gluten. For this reason, many gluten-free breads are based on rice flours or blends that contain rice flour.
- Short grain or pearl rice is also used in the pastry shop to produce rice pudding and other desserts.

Oats

Oats are widely used for animal feed and food production, as well as for making breads, cookies, and dessert toppings. Oats add texture to baked goods and desserts.

Varieties Used in Baking

- Bakers will most often encounter rolled oats, which are produced by pressing the de-husked whole kernels through rollers.
- Oat bran and oat flour are produced by grinding the oat kernels and separating out the bran and endosperm.
- Whole grain oat flour is produced by grinding the whole kernel but leaving the ground flour intact.
- Steel-cut oats are more commonly used in cooking and making breakfast cereals, and are the chopped oat kernels.

Other Grains and Pulses

A wide range of additional flours and grains that are used in ethnic cooking and baking are becoming more and more widely available in Canada. These may be produced from grains (such as kamut, spelt, and quinoa), pulses (such as lentils and chickpeas), and other crops (such as buckwheat) that have a grain-like consistency when dried. Increasingly, with allergies and intolerances on the rise, these flours are being used in bakeshops as alternatives to wheat-based products for customers with special dietary needs.
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Understanding Ingredients: Fat

Understanding Fats and Oils

Fats and oils are organic compounds that, like carbohydrates, are composed of the elements carbon (C), hydrogen (H), and oxygen (O), arranged to form molecules. There are many types of fats and oils and a number of terms and concepts associated with them, which are detailed further here.

Lipids

In baking, lipids are generally a synonym for fats. Baking books may talk about the "lipid content of eggs," for example.

Triglycerides

Triglycerides is another chemical name for the most common type of fats found in the body, indicating that they are usually made up of three (tri) fatty acids and one molecule of glycerol (glycerine is another name) as shown in Figure 3. (The mono and diglycerides that are used as emulsifiers have one and two fatty acids respectively.)

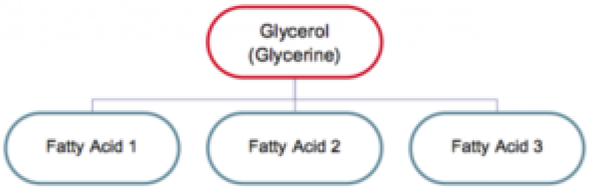


Figure 1 *Composition of fats (triglycerides)*

Fatty Acids

Each kind of fat or oil has a different combination of fatty acids. The nature of the fatty acid will determine the consistency of the fat or oil. For example, stearic acid is the major fatty acid in beef fat, and linoleic acid is dominant in seed oils. Fatty acids are defined as short, medium, or long chain, depending on the number of atoms in the molecule.

The reason that some fat melts gradually is that as the temperature rises, each fatty acid will, in turn, soften, as its melting point is reached. Fats that melt all of a sudden mean that the fatty acids are of the same or similar type and have melting points within a narrow range. An example of such a fat is coconut fat: one second it is solid, the next, liquid.

Table 1 shows the characteristics of three fatty acids.

Table 1: Characteristics of Fatty Acids

Type of Fatty Acid	**Melting Point**	**Physical State (at room temperature)**
Stearic	69°C (157°F)	Solid
Oleic	16°C (61°F)	Liquid
Linoleic	-12°C (9°F)	Liquid

Rancid

Rancid is a term used to indicate that fat has spoiled. The fat takes on an unpleasant flavor when exposed to air and heat. Unsalted butter, for example, will go rancid quickly if left outside the refrigerator, especially in warm climates.

Oxidation/Antioxidants

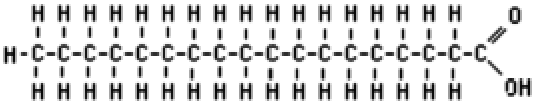
Oxidation (exposure to air) causes rancidity in fats over time. This is made worse by combination with certain metals, such as copper. This is why doughnuts are never fried in copper pans!

Some oils contain natural antioxidants, such as tocopherols (vitamin E is one kind), but these are often destroyed during the processing. As a result, manufacturers add synthetic antioxidants to retard rancidity. BHA and BHT are synthetic antioxidants commonly used by fat manufacturers.

Saturated/Unsaturated

Saturated and unsaturated refer to the extent to which the carbon atoms in the molecule of fatty acid are linked or bonded (saturated) to hydrogen atoms. One system of fatty acid classification is based on the number of double bonds.

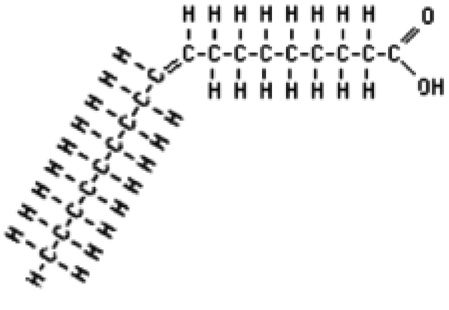
- 0 double bonds: saturated fatty acids. Stearic acid is a typical long-chain saturated fatty acid (Figure 2).[1]



Stearic acid, a saturated fatty acid

Figure 2 *Stearic Acid*

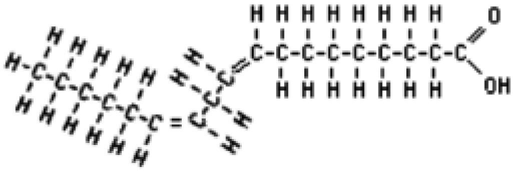
- 1 double bond: monounsaturated fatty acids. Oleic acid is a typical monounsaturated fatty acid (Figure 3).[2]



Oleic acid, a monounsaturated fatty acid. Note that the double bond is *cis*; this is the common natural configuration.

Figure 3 *Oleic Acid*

- 2 or more double bonds: polyunsaturated fatty acids. Linoleic acid is a typical polyunsaturated fatty acid (Figure 4).[3]



Linoleic acid, a polyunsaturated fatty acid.
Both double bonds are *cis*.

Figure 4 *Linoleic Acid*

Saturated fat is a type of fat found in food. For many years, there has been a concern that saturated fats may lead to an increased risk of heart disease; however, there have been studies to the contrary and the literature is far from conclusive. The general assumption is that the less saturated fat the better as far as health is concerned. For the fat manufacturer, however, low saturated fat levels make it difficult to produce oils that will stand up to the high temperatures necessary for processes such as deep-frying. Hydrogenation has been technology's solution. Hydrogenation will be discussed later in the chapter.

Saturated fat is found in many foods:

- Animal foods (like beef, chicken, lamb, pork, and veal)
- Coconut, palm, and palm kernel oils
- Dairy products (like butter, cheese, and whole milk)
- Lard
- Shortening

Unsaturated fat is also in the foods you eat. Replacing saturated and trans fats (see below) with unsaturated fats has been shown to help lower cholesterol levels and may reduce the risk of heart disease. Unsaturated fat is also a source of omega-3 and omega-6 fatty acids, which are generally referred to as "healthy" fats. Choose foods with unsaturated fat as part of a balanced diet using the U.S. Department of Health and Human Service's Dietary Guidelines.

Even though unsaturated fat is a "good fat," having too much in your diet may lead to having too many calories, which can increase your risk of developing obesity, type 2 diabetes, heart disease, and certain types of cancer.

There are two main types of unsaturated fats:

- Monounsaturated fat, which can be found in:
    - Avocados
    - Nuts and seeds (like cashews, pecans, almonds, and peanuts)
    - Vegetable oils (like canola, olive, peanut, safflower, sesame, and sunflower)
- Polyunsaturated fat, which can be found in:
    - Fatty fish (like herring, mackerel, salmon, trout and smelt)
    - Fish oils
    - Nuts and seeds (like cashews, pecans, almonds and peanuts)
    - Vegetable oils (like canola, corn, flaxseed, soybean and sunflower)

Hydrogenation

Simply put, hydrogenation is a process of adding hydrogen gas to alter the melting point of the oil or fat. The injected hydrogen bonds with the available carbon, which changes liquid oil into solid fat. This is practical, in that it makes fats versatile. Think of the different temperature conditions within a bakery during which fat must be workable; think of the different climatic conditions encountered in bakeries.

Trans Fat

Trans fat is made from a chemical process known as “partial hydrogenation.” This is when liquid oil is made into a solid fat. Like saturated fat, trans fat has been shown to raise LDL or “bad” cholesterol levels, which may in turn increase your risk for heart disease. Unlike saturated fat, trans fat also lowers HDL or “good” cholesterol. A low level of HDL-cholesterol is also a risk factor for heart disease.

Until recently, most of the trans fat found in a typical American diet came from:

- Fried foods (like doughnuts)
- baked goods including cakes, pie crusts, biscuits, frozen pizza, cookies, and crackers
- stick margarine and other spreads

The US Food and Drug Administration (FDA) specifically prescribe what information must be displayed on a label. The *trans fat* content of food is one piece of core nutrition information that is required to be declared in a nutrition facts table. More information on a nutrition facts table and labeling details can be found in http://www.fda.gov/food/ingredientspackaginglabeling/labelingnutrition/ucm274590.htm

Emulsification (Emulsified Shortenings)

Emulsification is the process by which normally unmixable ingredients (such as oil and water) can be combined into a stable substance. Emulsifiers are substances that can aid in this process. There are natural emulsifiers such as lecithin, found in egg yolks. Emulsifiers are generally made up of monoglycerides and diglycerides and have been added to many hydrogenated fats, improving the fat’s ability to:

- Develop a uniformly fine structure
- Absorb a high percentage of sugar
- Hold in suspension a high percentage of liquid

Emulsified shortenings are ideal for cakes and icings, but they are not suitable for deep-frying.

Stability

Stability refers to the ability of a shortening to have an extended shelf life. It refers especially to deep-frying fats, where a smoke point (see below) of 220°C to 230°C (428°F to 446°F) indicates a fat of high stability.

Smoke Point

The smoke point is the temperature reached when fat first starts to smoke. The smoke point will decline over time as the fat breaks down (see below).

Fat Breakdown

The technical term for fat breakdown is hydrolysis, which is the chemical reaction of a substance with water. In this process, fatty acids are separated from their glycerol molecules and accumulate over time in the fat. When their concentration reaches a certain point, the fat takes on an unpleasant taste, and continued use of the fat will yield a nasty flavor. The moisture, which is at the root of this problem, comes from the product being fried. This is why it is a good reason to turn off the fryer or turn it to “standby” between batches of frying foods such as doughnuts. Another cause of fat breakdown is excessive flour on the product or particles breaking off the product.

Attribution

Figure 2. Stearic Acide. Retrieved from http://library.med.utah.edu/NetBiochem/FattyAcids/3_3.html ↵

Figure 3 Oleic Acid Retrieved from: http://library.med.utah.edu/NetBiochem/FattyAcids/3_3.html ↵

Figure 4 Linoleic Acid Retrieved from: http://library.med.utah.edu/NetBiochem/FattyAcids/3_3.html ↵

34

Sources of Bakery Fats and Oils

Edible fats and oils are obtained from both animal and vegetable sources. Animal sources include:

- Beef
- Pork
- Sheep
- Fish

In North America, the first two are the prime sources.

Vegetable sources include canola, coconut, corn, cotton, olive, palm fruit and palm kernel, peanut, soya bean, safflower, and sunflower.

Refining of Fats and Oils

The major steps in refining fats and oils are as follows:

- Free fatty acids are neutralized and treated with an alkali.
- Color is removed.
- The fat is hydrogenated.
- The fat is deodorized.
- The fat is chilled and beaten to make it softer and whiter. This is done by a votator (a machine that cools and kneads liquid margarine).
- Fat is stored to facilitate the correct crystallization (tempering).

Attribution

35

Major Fats and Oils Used in Bakeries

Lard

Lard is obtained from the fatty tissues of pigs, with a water content of 12% to 18%. Due to dietary concerns, lard has gradually lost much of its former popularity. It is still extensively used, however, for:

- Yeast dough additions
- Pie pastry
- Pan greasing

Lard has a good plastic range, which enables it to be worked in a pie dough at fairly low temperatures (try the same thing with butter!). It has a fibrous texture and does not cream well. It is therefore not suitable for cake making. Some grades of lard also have a distinctive flavor, which is another reason it is unsuitable for cake making.

Butter

Butter is made from sweet, neutralized, or ripened creams pasteurized and standardized to a fat content of 30% to 40%. When cream is churned or overwhipped, the fat particles separate from the watery liquid known as buttermilk. The separated fat is washed and kneaded in a water wheel to give it plasticity and consistency. Color is added during this process to make it look richer, and salt is added to improve its keeping quality.

In Canada, the following regulations apply to butter:

- Minimum 80% milk fat by weight
- Permitted ingredients: milk solids, salt, air or inert gas, permitted food color, permitted bacterial culture
- The grade and grade name for butter and butter products is Canada 1.

Sweet (or unsalted) butter is made from a cream that has a very low acid content and no salt is added to it. It is used in some baking products like French butter cream, where butter should be the only fat used in the recipe. Keep sweet butter in the refrigerator.

From the standpoint of flavor, butter is the most desirable fat used in baking. Its main drawback is its relatively high cost. It has moderate but satisfactory shortening and creaming qualities. When used in cake mixing, additional time, up to five minutes more, should be allowed in the creaming stage to give maximum volume. Adding an emulsifier (about 2% based on flour weight) will also help in cake success, as butter has a poor plastic range of 18°C to 20°C (64°F to 68°F).

Butter and butter products may also be designated as “whipped” where they have had air or inert gas uniformly incorporated into them as a result of whipping. Whipped butter may contain up to 1% added edible casein or edible caseinates.

Butter and butter products may also be designated as “cultured” where they have been produced from cream to which a permitted bacterial culture has been added.

Margarine

Margarines are made primarily from vegetable oils (to some extent hydrogenated) with a small fraction of milk powder and bacterial culture to give a butter-like flavor. Margarines are very versatile and include:

- General purpose margarine with a low melting point, suitable for blending in dough and general baking
- Cake margarine with excellent creaming qualities
- Roll-in margarine, which is plastic and suitable for Danish pastries
- Puff pastry roll-in, which is the most waxy and has the highest melting point

Margarine may be obtained white, but is generally colored. Margarine has a fat content ranging from 80% to 85%, with the balance pretty much the same as butter.

Oil content claims on margarine

The claim that margarine contains a certain percentage of a specific oil in advertisements should always be based on the percentage of oil by weight of the total product. All the oils used in making the margarine should be named. For example, if a margarine is made from a mixture of corn oil, cottonseed oil, and soybean oil, it would be considered misleading to refer only to the corn oil content in an advertisement for the margarine. On the other hand, the mixture of oils could be correctly referred to as vegetable oils.

It used to be that you could only buy margarines in solid form full of saturated and trans fat. The majority of today’s margarines come in tubs, are soft and spreadable, and are non-hydrogenated, which means they have low levels of saturated and trans fat. Great care must be taken when attempting to substitute spreadable margarine for solid margarine in recipes.

Shortenings

Since the invention of hydrogenated vegetable oil in the early 20th century, *shortening* has come almost exclusively to mean hydrogenated vegetable oil. Vegetable shortening shares many properties with lard: both are semi-solid fats with a higher smoke point than butter and margarine. They contain less water and are thus less prone to splattering, making them safer for frying. Lard and shortening have a higher fat content (close to 100%) compared to about 80% for butter and margarine. Cake margarines and shortenings tend to contain a bit higher percentage of monoglycerides that margarines. Such “high-ratio shortenings” blend better with hydrophilic (attracts water) ingredients such as starches and sugar.

Health concerns and reformulation

Early in this century, vegetable shortening became the subject of some health concerns due to its traditional formulation from partially hydrogenated vegetable oils that contain trans fats, which have been linked to a number of adverse health effects. Consequently, a low trans-fat variant of Crisco brand shortening was introduced in 2004. In January 2007, all Crisco products were reformulated to contain less than one gram of trans fat per serving, and the separately marketed trans-fat free version introduced in 2004 was consequently discontinued. Since 2006, many other brands of shortening have also been reformulated to remove trans fats. Non-hydrogenated vegetable shortening can be made from palm oil.

Hydrogenated vegetable shortenings

Hydrogenated shortenings are the biggest group of fats used in the commercial baking industry. They feature the following characteristics:

- They are made from much the same oils as margarine.
- They are versatile fats with good creaming ability.
- Their hydrogenation differs according to the specific use for which the fat is designed.
- They are 100% fat – no water.
- They keep well for six to nine months.

Variations on these shortenings are: emulsified vegetable shortenings, roll-in pastry shortenings, and deep-frying fats.

Emulsified vegetable shortenings

Emulsified vegetable shortenings are also termed *high-ratio fats*. The added emulsifiers (mono- and diglycerides) increase fat dispersion and give added fineness to the baked product. They are ideal for high-ratio cakes, where relatively large amounts of sugar and liquid are incorporated. The result is a cake:

- Fine in texture
- Light in weight and of excellent volume
- Superior in moisture retention (good shelf life)
- Tender to eat

This is also the fat of choice for many white cake icings.

Roll-in pastry shortenings

This type of shortening is also called special pastry shortening (SPS). These fats have a semi-waxy consistency and offer:

- Large plastic range
- Excellent extensibility
- Excellent lifting ability

They are primarily used in puff pastry and Danish pastry products where lamination is required. They come in various specialized forms, with varying qualities and melting points. It is all a matter of compromise between cost, palatability, and leavening power. A roll-in that does not have "palate cling" may have a melting point too low to guarantee maximum lift in a puff pastry product.

Deep-Frying Fats

Deep-frying fats are special hydrogenated fats that have the following features:

- High smoke point of up to 250°C (480°F)
- High heat stability and resistance to fat breakdown
- No undesirable flavor on finished products
- No greasiness when cold

These fats contain an anti-foaming agent.

Vegetable Oils

Vegetable oil is an acceptable common name for an oil that contains more than one type of vegetable oil. Generally, when such a vegetable oil blend is used as an ingredient in another food, it may be listed in the ingredients as "vegetable oil."

There are two exceptions: if the vegetable oils are ingredients of a cooking oil, salad oil, or table oil, the oils must be specifically named in the ingredient list (e.g., canola oil, corn oil, safflower oil), and using the general term *vegetable oil* is not acceptable. As well, if any of the oils are coconut oil, palm oil, palm kernel oil, peanut oil, or cocoa butter, the oils must be specifically named in the ingredient list.

When two or more vegetable oils are present and one or more of them has been modified or hydrogenated, the common name on the principal display panel and in the list of ingredients must include the word "modified" or "hydrogenated," as appropriate (e.g., modified vegetable oil, hydrogenated vegetable oil, modified palm kernel oil).

Vegetable oils are used in:

- Chemically leavened batters (e.g., muffin mixes)
- Dough additives (to replace the fat)
- Short sponges (to replace the butter or fat)

Coconut Fat

Coconut fat is often used to stabilize butter creams as it has a very small plastic range. It has a quite low melting point and its hardness is due to other factors. It can be modified to melt at different temperatures, generally between 32°C and 36°C (90°F and 96°F).

The Importance of Melting Points

As mentioned above, all fats become oils and vice versa, depending on temperature. Physically, fats consist of minute solid fat particles enclosing a microscopic liquid oil fraction. The consistency of fat is very important to the baker. It is very difficult to work with butter (relatively low melting point) in hot weather, for example. At the other extreme, fats with a very high melting point are not very palatable, since they tend to stick to the palate. Fat manufacturers have therefore attempted to customize fats to accommodate the various needs of the baker.

Fats with a melting range between 40°C and 44°C (104°F and 112°F) are considered to be a good compromise between convenience in handling and palatability. New techniques allow fats with quite high melting points without unpleasant palate-cling.

Table 1 shows the melting points of some fats.

Table 1 Melting points of typical fats.

Type of Fat	**Melting Point**
Coconut fat	32.5°C-34.5°C (90.5°F-4.1°F)
Regular margarine	34°C (93°F)
Butter	38°C (100°F)
Regular shortenings	44°C-47°C (111°F-116°F)
Roll-in shortenings	40°C-50°C (104°F-122°F)
Roll-in margarine	44°C-54°C (111°F-130°F)

Blending

It is probably safe to say that most fats are combinations or blends of different oils and/or fats.

They may be all vegetable sources. They may be combined vegetable and animal sources. A typical ratio is 90% vegetable source to 10% animal (this is **not** a hard and fast rule). Formerly, blends of vegetable and animal oils and fats were termed *compound fats*. Nowadays, this term, if used at all, may refer also to combinations of purely vegetable origin.

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36

Functions of Fat in Baking

The following summarize the various functions of fat in baking.

Tenderizing Agents

Used in sufficient quantity, fats tend to “shorten” the gluten strands in flour; hence their name: shortenings. Traditionally, the best example of such fat was lard.

Creaming Ability

This refers to the extent to which fat, when beaten with a paddle, will build up a structure of air pockets. This aeration, or creaming ability, is especially important for cake baking; the better the creaming ability, the lighter the cake.

Plastic Range

Plastic range relates to the temperature at which the fatty acid component melts and over which shortening will stay workable and will “stretch” without either cracking (too cold) or softening (too warm). A fat that stays “plastic” over a temperature range of 4°C to 32°C (39°F to 90°F) would be rated as excellent. A dough made with such a fat could be taken from the walk-in cooler to the bench in a hot bakeshop and handled interchangeably. Butter, on the other hand, does not have a good plastic range; it is almost too hard to work at 10°C (50°F) and too soft at 27°C (80°F).

Lubrication

In dough making, the fat portion makes it easier for the gluten network to expand. The dough is also easier to mix and to handle. This characteristic is known as *lubrication*.

Moistening Ability

Whether in dough or in a cake batter, fat retards drying out. For this purpose, a 100% fat shortening will be superior to either butter or margarine.

Nutrition

As one of the three major food categories, fats provide a very concentrated source of energy. They contain many of the fatty acids essential for health.
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Understanding Ingredients: Sugar

37

Sugar Chemistry (ADD US)

Chemically, sugar consists of carbon (C), oxygen (O), and hydrogen (H) atoms, and is classified as a **carbohydrate**. There are three main groups of sugars, classified according to the way the atoms are arranged together in the molecular structure. These groups are the following:

- **Monosaccharides** or simple sugars. **Dextrose** (**glucose**) is the major monosaccharide. Others are **levulose** or **fructose** (found in **honey** and many fruits), and galactose, which is a milk sugar. Such sugars do not readily crystallize. (*Mono* means *one*, indicating that the sugar consists of only one molecule.)
- **Disaccharides** or complex sugars. Sucrose (common sugar) is the primary example of a disaccharide. Maltose, found in cereals, and **lactose**, found in milk, are others.
- **Polysaccharides.** Examples are starches, dextrins, and cellulose.

Bakers are not concerned with polysaccharides but rather with the monosaccharides and disaccharides. The latter two both sweeten, but they cannot be used interchangeably because they have different effects on the end product. These differences are touched on later in the book.

Sugar Names

It is helpful to understand some of the conventions of the names of different sugars. Note that sugar names often end in "ose": sucrose, dextrose, maltose, lactose, etc. **Sucrose** is the chemical name for sugar that comes from the cane and beet sugar plants.

Note that glucose is the chemical name for a particular type of sugar. What is sometimes confusing is that glucose occurs naturally, as a sugar molecule in substances such as honey, but it is also produced industrially from the maize plant (corn).

The Canadian Food and Drug Regulations (FDR) govern the following definitions:

- Sugars: All monosaccharides and disaccharides. Used for nutrition labelling purposes.
- Sweetening agent: Any food for which a standard is provided in Division 18 of the Food and Drug Regulation, or any combination of these. Includes sugar (sucrose), sugar syrups, and molasses derived from sugar cane or sugar beet, dextrose, glucose and syrups, honey and lactose. Excludes sweeteners considered to be food additives.
- Sweetening ingredient: Any sugar, **invert sugar**, honey, dextrose, glucose, or glucose solids, or any combination of these in dry or liquid form. Designed for sweetening fruits, vegetables, and their products and substitutes.
- Maple syrup: The syrup obtained by the concentration of maple sap or by the dilution or solution of a maple product, other than maple sap, in potable water.
- Sweetener: Any food additive listed as a sweetener. Includes both sugar alcohols and high intensity-sweeteners such as acesulfame-potassium, aspartame, and sucralose.
- Sugar alcohols: Food additives that may be used as sweeteners. Includes isomalt, lactitol, maltitol, maltitol syrup, mannitol, sorbitol, sorbitol syrup, xylitol, and erythritol.

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38

Sugar Refining

While some refining usually occurs at source, most occurs in the recipient country. The raw sugar that arrives at the ports is not legally edible, being full of impurities.

At the refinery, the raw brown sugar goes through many stages:

- Washing and boiling
- Filtering to remove impurities
- Evaporation to the desired crystal size under vacuum to avoid caramelization
- Centrifuging, in which the fluid is spun off leaving the crystals
- Drying in a rotating drum with hot air
- Packaging in various sizes, depending on the intended market

Sugar beet undergoes identical steps after the initial processing, which involves:

- Slicing the beets and extracting the sugar with hot water
- Removing impurities
- Filtration
- Concentration in evaporators

From here, the process is identical to the final steps in cane processing. See Figure 2 which illustrates the process.

Some of the sugar passes through a machine that presses the moist sugar into cubes and wraps and packages them; still other sugar is made into icing sugar. The sugar refining process is completely mechanical, and machine operators' hands never touch the sugar.

Brown and yellow sugars are produced only in cane sugar refineries. When sugar syrup flows from the centrifuge machine, it passes through further filtration and purification stages and is re-boiled in vacuum pans such as the two illustrated in Figure 2. The sugar crystals are then centrifuged but not washed, so the sugar crystals still retain some of the syrup that gives the product its special flavour and colour.

During the whole refining process almost 100 scientific checks for quality control are made, while workers in research laboratories at the refineries constantly carry out experiments to improve the refining process and the final product. Sugar is carefully checked at the mills and is guaranteed to have a high purity. Government standards both in the United States and Canada require a purity of at least 99.5% sucrose.

Are animal ingredients included in white sugar?

Bone char — often referred to as natural carbon — is widely used by the sugar industry as a decolourizing filter, which allows the sugar cane to achieve its desirable white colour. Other types of filters involve granular carbon or an ion-exchange system rather than bone char.

Bone char is made from the bones of cattle, and it is heavily regulated by the European Union and the USDA. Only countries that are deemed BSE-free can sell the bones of their cattle for this process.

Bone char is also used in other types of sugar. Brown sugar is created by adding molasses to refined sugar, so companies that use bone char in the production of their regular sugar also use it in the production of their brown sugar. Confectioner's sugar — refined sugar mixed with cornstarch — made by these companies also involves the use of bone char. Fructose may, but does not typically, involve a bone-char filter.

Bone char is not used at the sugar beet factory in Taber, Alberta, or in Montreal’s cane refinery. Bone char is used only at the Vancouver cane refinery. All products under the Lantic trademark are free of bone char. For the products under the Rogers trademark, all Taber sugar beet products are also free of bone char. In order to differentiate the Rogers Taber beet products from the Vancouver cane products, you can verify the inked-jet code printed on the product. Products with the code starting with the number “22” are from Taber, Alberta, while products with the code starting with the number “10” are from Vancouver.

If you want to avoid all refined sugars, there are alternatives such as sucanat and turbinado sugar, which are not filtered with bone char. Additionally, beet sugar — though normally refined — never involves the use of bone char.

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39

The Application of Sugar

Sugar is the third most used ingredient in the bakeshop. Sugar has several functions in baking. The most recognized purpose is, of course, to sweeten food, but there are many other reasons sugar is used in cooking and baking:

- It can be used for browning effect, both **caramelization** and the **Maillard reaction**, on everything from breads to cookies to cakes. Browning gives a pleasant colour and flavour to the finished product. Caramelization results from the action of heat on sugars. At high temperatures, the chemical changes associated with melting sugars result in a deep brown colour and new flavours. The Maillard reaction results from chemical interactions between sugars and proteins at high heat. An amino group from a protein combines with a reducing sugar to produce a brown colour in a variety of foods (e.g., brewed coffee, fried foods, and breads).
- It acts as the most important tenderizing agent in all baked goods, and one of the factors responsible for the spread in cookies. It helps delay the formation of gluten, which is essential for maintaining a soft or tender product.
- It makes an important contribution to the way we perceive the texture of food. For example, adding sugar to ice cream provides body and texture, which is perceived as smoothness. This addition helps prevent lactose crystallization and thus reduces sugar crystal formation that otherwise causes a grainy texture sometimes associated with frozen dairy products.
- It preserves food when used in sufficient quantity.
- In baking, it increases the effectiveness of yeast by providing an immediate and more usable source of nourishment for the yeast’s growth. This hastens the leavening process by producing more carbon dioxide, which allows the dough to rise at a quicker and more consistent rate.

Just as there are many functions of sugar in the bakeshop, there are different uses for the various types of sugar as well:

- Fine granulated sugar is most used by bakers. It generally dissolves easily in mixes and is pure enough for sugar crafters to boil for “pulled” sugar decorations.
- Coarse granulated sugar may be used for a topping on sugar cookies, puff pastry, and Danish pastries as it doesn’t liquefy or caramelize so readily. In some European countries, an extra coarse sugar (called *hail* — a literal translation) is used for this purpose.
- Icing or powdered sugar is used in icings and fillings and in sifted form as a top decoration on many baked goods.
- Brown or yellow sugars are used where their unique flavour is important, or in bakeries where an old-fashioned or rustic image is projected. Brown sugar can usually be substituted for white sugar without technical problems in sugar/batter mixes such as cakes and muffins, and in bread dough.

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40

Agave

Agave has gained popularity in the food industry due to some of its nutritional properties. The agave nectar is obtained from the sap of the heart of the agave plant, a desert succulent, which is also used to produce tequila. The syrup/sugar production process of agave is similar to that of sugar. See more about the nutritional properties and application of agave in the chapter Special Diets, Allergies, Intolerances, Emerging Issues, and Trends in the open textbook *Nutrition and Labelling for the Canadian Baker*.

A video on the production of agave syrup is available here: https://www.youtube.com/watch?v=DZ2moGQL6n8
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Glucose/Dextrose

The sugar known as glucose has two origins:

- In a natural form in most fruits
- In a processed form from corn (corn syrup)

In baking, we usually refer to industrially made glucose. It is made from corn and the resulting product, a thick syrup, is then adjusted to a uniform viscosity or consistency. The particular form of the syrup is defined by what is known as the *dextrose equivalent,* or DE for short. Corn syrup is the most familiar form of glucose.

In plant baking, high-fructose corn syrup (HFCS) is the major sweetening agent in bread and buns. It consists of roughly half fructose and half dextrose. Dextrose (chemically identical to glucose) is available in crystalline form and has certain advantages over sucrose:

- It is easily fermentable.
- It contributes to browning in bread and bun making.
- In crystalline form, it is often used in doughnut sugars as it is more inclined to stay dry and non-greasy.
- It is **hygroscopic** and valued as a moisture-retaining ingredient.
- It retards crystallization in syrups, candies, and fondant.

Corn syrup is made from the starch of maize (corn) and contains varying amounts of glucose and maltose, depending on the processing methods. Corn syrup is used in foods to soften texture, add volume, prevent crystallization of sugar, and enhance flavor.

Glucose/dextrose has a sweetening level of approximately three-quarters that of sugar. Table 1 shows the amount of corn syrup or HFCS needed to replace sugar in a formula.

Table1 Replacement factor for Corn Syrup and High-Fructose Corn Syrup

Type of Sugar	Solids	Replacement Factor
Granulated sugar	100%	1.0
Regular corn syrup	80%	1.25
High-fructose corn syrup	71%	1.41

Glucose, HFCS, and corn syrup are not appropriate substitutions for sucrose in all bakery products. Certain types of cakes, such as white layer cakes, will brown too much if glucose or HFCS is used in place of sugar.
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42

Honey

Honey is a natural food, essentially an invert sugar. Bees gather nectar and, through the enzyme invertase, change it into honey. Honey varies in composition and flavor depending on the source of the nectar. The average composition of honey is about 40% levulose, 35% dextrose, and 15% water, with the remainder being ash, waxes, and gum.

Blended honey is a mixture of pure honey and manufactured invert sugar, or a blend of different types of honey mixed together to produce a good consistency, color, and aroma. Dehydrated honey is available in a granular form.

Store honey in a tightly covered container in a dry place and at room temperature because it is hygroscopic, meaning it absorbs and retains moisture. Refrigeration or freezing won’t harm the color or flavor but it may hasten granulation. Liquid honey crystallizes during storage and is re-liquefied by warming in a double boiler not exceeding a temperature of 58°C (136°F).

Honey is used in baking:

- As a sweetener
- To add unique flavor
- In gingerbread and special cookies where a certain moistness is characteristic of the product
- To improve keeping qualities

There are several types of honey available:

- Comb honey is “packed by the bees” directly from the hive.
- Liquid honey is extracted from the comb and strained. It is the type used by most bakers.
- Creamed honey has a certain amount of crystallized honey added to liquid honey to give body to the final product.
- Chunk honey consists of pieces of comb honey as well as liquid.
- Granulated honey has been crystallized.

In the United States, honey categories are based on color, from white to dark amber. Honey from orange blossom is an example of white honey. Clover honey is an amber honey, and sage and buckwheat honeys are dark amber honeys.
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43

Malt

Malt is the name given to a sweetening agent made primarily from barley. The enzymes from the germ of the seeds become active, changing much of the starch into maltose, a complex sugar. Maltose has a distinct flavor and is used for making yeast products such as bread and rolls. Malt is considered to be relatively nutritious compared to other sweeteners.

Malt is available as:

- Flour
- Malt syrup
- Malt extract
- Dried malt

The flour is not recommended since it can lead to problems if not scaled precisely. Malt syrup is inconvenient to work with, as it is sticky, heavy, and bulky. Dried malt is the most practical, though it must be kept protected from humidity.

There are two distinct types of malt:

- Diastatic malt flour is dried at low temperature, thus retaining the activity of the diastatic enzymes.
- Non-diastatic malt flour is darker in color. It is treated at high temperature, which kills the enzymes, and the result is non-diastatic malt.

Crushing malted grain in water produces malt syrup. This dissolves the maltose and soluble enzymes. The liquid is concentrated, producing the syrup. If the process is continued, a dry crystallized product called dried malt syrup is obtained.

Malt syrup has a peculiar flavor, which many people find desirable. It is used in candy, malted milk, and many other products. The alcoholic beverage industry is the largest consumer of malt by far, but considerable quantities are used in syrup and dried malt syrup, both of which are divided into diastatic and non-diastatic malt.

Both diastatic and non-diastatic malts add sweetness, color, and flavor to baked products. Both are valuable since they contain malt sugar, which is fermented by the yeast in the later stages of fermentation. Other sugars such as glucose and levulose are used up rapidly by fermenting yeast in the early stages of fermentation.

Diastatic malt is made with various levels of active enzymes. Malt with medium diastatic activity is recommended. Normally, bread bakers will find sufficient enzymes in well-balanced flour from a good mill, so it is unnecessary to use diastatic malt.

When using dry diastatic malt, about the same weight should be used as liquid regular diastatic malt. Adjustment is made at the factory insofar as the enzyme level is increased in the dry product to compensate. Since the dry type contains about 20% less moisture than the liquid type, add water to make up the difference if dry diastatic malt is substituted for malt syrup.

The main uses of malt in the bakery are to:

- Add nutritive value, as it is rich in vitamins and essential amino acids
- Lengthen shelf life through its ability to attract moisture

- Help fermentation by strengthening the gluten and feeding the yeast
- Make products more appealing through browning of the crust
- Add unique flavor to products when used in sufficient quantity

Table 1 shows the suggested use levels for malt.

Table 1 Recommended level of malt for various baked goods

Product	**Percentage of Flour Weight**
White pan bread	0.5-1.5
Sweet goods	1.5-3.0
French/Italian bread	0.5-2.0
Whole wheat bread	5.0-9.0
Pretzels	1.5-6.0
Hard rolls	3.0-5.5

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44

Maple Syrup (ADD US)

Canada is responsible for 84% of the world’s maple syrup production, with the United States being responsible for the remaining 16%. Maple syrup is made by boiling and evaporating the sap of the sugar maple tree. Because sap is only 2% or 3% sugar, it takes almost 40 liters of sap to make 1 liter of syrup. This makes maple syrup a very expensive sweetener. It is prized for its unique flavor and sweet aroma. Don’t confuse maple-flavored pancake or table syrup with real maple syrup. Table syrup is made from inexpensive glucose or corn syrup, with added caramel coloring and maple flavoring.

Maple syrup in Canada has two categories:

- Canada Grade A, which has four color/flavor classes
  - (i) golden, delicate taste
  - (ii) amber, rich taste
  - (iii) dark, robust taste
  - (iv) very dark, strong taste
- Canada Processing Grade, which has no color descriptors (any maple syrup that possesses minimal food quality defects but still meets all government regulatory standards for food quality and safety for human consumption)

This definition and grading system gives consumers more consistent and relevant information about the varieties, and helps them make informed choices when choosing maple syrup.

Darker maple syrups are better for baking as they have a more robust flavor. Using maple sugar is also a good way to impart flavor. Maple sugar is what remains after the sap of the sugar maple is boiled for longer than is needed to create maple syrup. Once almost all the water has been boiled off, all that is left is a solid sugar. It can be used to flavor some maple products and as an alternative to cane sugar.

For a video on maple syrup production, see: https://www.youtube.com/watch?v=OFIj4pMYpTQ

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45

Sugar Substitutes (ADD US)

In Canada, food additives such as sugar substitutes, which cover both artificial sweeteners and intense sweeteners obtained from natural sources, are subject to rigorous controls under the Food and Drugs Act and Regulations. New food additives (or new uses of permitted food additives) are permitted only once a safety assessment has been conducted and regulatory amendments have been enacted.

Several sugar substitutes have been approved for use in Canada. These include acesulfame-potassium, aspartame, polydextrose, saccharin, stevia, sucralose, thaumatin, and sugar alcohols (polyols) like sorbitol, isomalt, lactitol, maltitol, mannitol, and xylitol. Please see the Health Canada website for more information on sugar substitutes.

Bakers must be careful when replacing sugar (sucrose) with these sugar substitutes in recipes. Even though the sweetness comparison levels may be similar (or less), it is generally not possible to do straight 1-for-1 substitution. Sugar (sucrose) plays many roles in a recipe:

- It is a bulking agent.
- It absorbs moisture.
- It is a tenderizer.
- It adds moisture and extends shelf life.
- It adds colour (caramelization).

Sugar substitutes may not work in a recipe in the same way.

More information on sugar substitutes and their relative sweetness can be found here:

http://www.sugar-and-sweetener-guide.com/sweetener-values.html
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Understanding Ingredients: Leavening Agents

Catalysis

Learning Objectives

By the end of this section, you will be able to:

- Explain the function of a catalyst in terms of reaction mechanisms and potential energy diagrams
- List examples of catalysis in natural and industrial processes

We have seen that the rate of many reactions can be accelerated by catalysts. A catalyst speeds up the rate of a reaction by lowering the activation energy; in addition, the catalyst is regenerated in the process. Several reactions that are thermodynamically favorable in the absence of a catalyst only occur at a reasonable rate when a catalyst is present. One such reaction is catalytic hydrogenation, the process by which hydrogen is added across an alkene C=C bond to afford the saturated alkane product. A comparison of the reaction coordinate diagrams (also known as energy diagrams) for catalyzed and uncatalyzed alkene hydrogenation is shown in Figure 1.

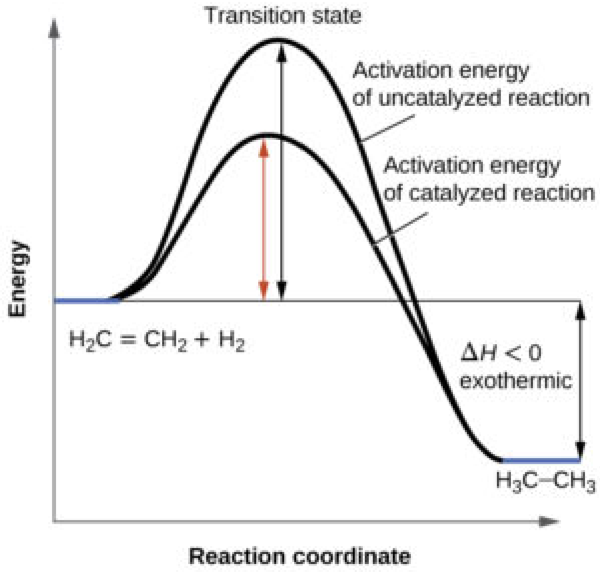


Figure 1 *This graph compares the reaction coordinates for catalyzed and uncatalyzed alkene hydrogenation.*

Catalysts function by providing an alternate reaction mechanism that has a lower activation energy than would be found in the absence of the catalyst. In some cases, the catalyzed mechanism may include additional steps, as depicted in the reaction diagrams shown in Figure 2. This lower activation energy results in an increase in rate as described by the Arrhenius equation. Note that a catalyst decreases the activation energy for both the forward and the reverse reactions and hence accelerates both the forward and the reverse reactions. Consequently, the presence of a catalyst will permit a system to reach equilibrium more quickly, but it has no effect on the position of the equilibrium as reflected in the value of its equilibrium constant (see the later chapter on chemical equilibrium).

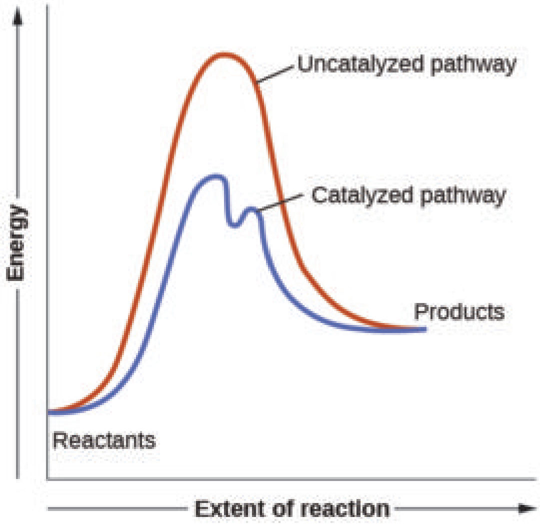
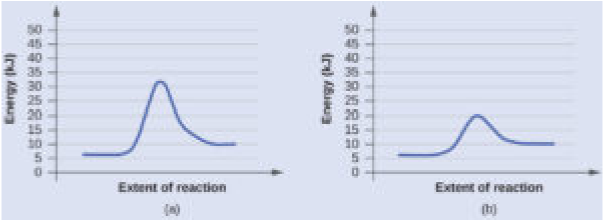


Figure 2 *This potential energy diagram shows the effect of a catalyst on the activation energy. The catalyst provides a different reaction path with a lower activation energy. As shown, the catalyzed pathway involves a two-step mechanism (note the presence of two transition states) and an intermediate species (represented by the valley between the two transitions states).*

Example 1: Using Reaction Diagrams to Compare Catalyzed Reactions

The two reaction diagrams here represent the same reaction: one without a catalyst and one with a catalyst. Identify which diagram suggests the presence of a catalyst, and determine the activation energy for the catalyzed reaction:



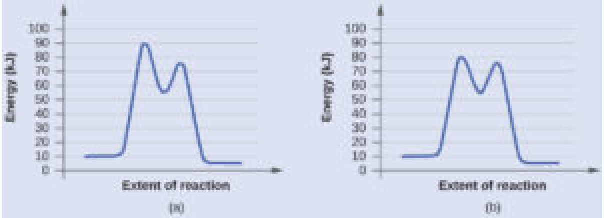
Solution

A catalyst does not affect the energy of reactant or product, so those aspects of the diagrams can be ignored; they are, as we would expect, identical in that respect. There is, however, a noticeable difference in the transition state, which is distinctly lower in diagram (b) than it is in (a). This indicates the use of a catalyst in diagram (b). The activation energy is the difference between the energy of the starting reagents and the transition state—a maximum on the reaction coordinate diagram. The reagents are at 6 kJ and the transition state is at 20 kJ, so the activation energy can be calculated as follows:

$E_a = 20\text{kJ} - 6\text{kJ} = 14\text{kJ}$

Check Your Learning

Determine which of the two diagrams here (both for the same reaction) involves a catalyst, and identify the activation energy for the catalyzed reaction:



Answer:

Diagram (b) is a catalyzed reaction with an activation energy of about 70 kJ.

Homogeneous Catalysts

A homogeneous catalyst is present in the same phase as the reactants. It interacts with a reactant to form an intermediate substance, which then decomposes or reacts with another reactant in one or more steps to regenerate the original catalyst and form product.

As an important illustration of homogeneous catalysis, consider the earth's ozone layer. Ozone in the upper atmosphere, which protects the earth from ultraviolet radiation, is formed when oxygen molecules absorb ultraviolet light and undergo the reaction:

$$3O_2(g) \xrightarrow{hv} 2O_3(g)$$

Ozone is a relatively unstable molecule that decomposes to yield diatomic oxygen by the reverse of this equation. This decomposition reaction is consistent with the following mechanism:

$$O_3 \longrightarrow O_2 + O$$

$$O + O_3 \longrightarrow 2O_2$$

The presence of nitric oxide, NO, influences the rate of decomposition of ozone. Nitric oxide acts as a catalyst in the following mechanism:

$$NO(g) + O_3(g) \longrightarrow NO_2(g) + O_2(g)$$

$$O_3(g) \longrightarrow O_2(g) + O(g)$$

$$NO_2(g) + O(g) \longrightarrow NO(g) + O_2(g)$$

The overall chemical change for the catalyzed mechanism is the same as:

$$2O_3(g) \longrightarrow 3O_2(g)$$

The nitric oxide reacts and is regenerated in these reactions. It is not permanently used up; thus, it acts as a catalyst. The rate of decomposition of ozone is greater in the presence of nitric oxide because of the catalytic activity of NO. Certain compounds that contain chlorine also catalyze the decomposition of ozone.

Note: Mario J. Molina

The 1995 Nobel Prize in Chemistry was shared by Paul J. Crutzen, Mario J. Molina (Figure 3), and F. Sherwood Rowland "for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone."[1] Molina, a Mexican citizen, carried out the majority of his work at the

Massachusetts Institute of Technology (MIT).

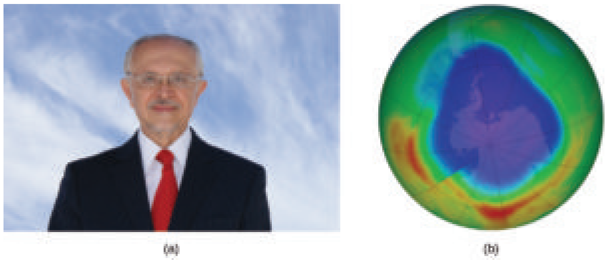


Figure 3 *(a) Mexican chemist Mario Molina (1943 –) shared the Nobel Prize in Chemistry in 1995 for his research on (b) the Antarctic ozone hole. (credit a: courtesy of Mario Molina; credit b: modification of work by NASA)*

In 1974, Molina and Rowland published a paper in the journal Nature (one of the major peer-reviewed publications in the field of science) detailing the threat of chlorofluorocarbon gases to the stability of the ozone layer in earth's upper atmosphere. The ozone layer protects earth from solar radiation by absorbing ultraviolet light. As chemical reactions deplete the amount of ozone in the upper atmosphere, a measurable "hole" forms above Antarctica, and an increase in the amount of solar ultraviolet radiation— strongly linked to the prevalence of skin cancers—reaches earth's surface. The work of Molina and Rowland was instrumental in the adoption of the Montreal Protocol, an international treaty signed in 1987 that successfully began phasing out production of chemicals linked to ozone destruction.

Molina and Rowland demonstrated that chlorine atoms from human-made chemicals can catalyze ozone destruction in a process similar to that by which NO accelerates the depletion of ozone. Chlorine atoms are generated when chlorocarbons or chlorofluorocarbons—once widely used as refrigerants and propellants—are photochemically decomposed by ultraviolet light or react with hydroxyl radicals. A sample mechanism is shown here using methyl chloride:

$CH_3Cl + OH \longrightarrow Cl + \text{other products}$

Chlorine radicals break down ozone and are regenerated by the following catalytic cycle:

$Cl + O_3 \longrightarrow ClO + O_2$

$ClO + O \longrightarrow Cl + O_2$

overall Reaction: $O_3 + O \longrightarrow 2O_2$

A single monatomic chlorine can break down thousands of ozone molecules. Luckily, the majority of atmospheric chlorine exists as the catalytically inactive forms Cl_2 and $ClONO_2$.

Since receiving his portion of the Nobel Prize, Molina has continued his work in atmospheric chemistry at MIT.

Note: Glucose-6-Phosphate Dehydrogenase Deficiency

Enzymes in the human body act as catalysts for important chemical reactions in cellular metabolism. As such, a deficiency of a particular enzyme can translate to a life-threatening disease. G6PD (glucose-6-phosphate dehydrogenase) deficiency, a genetic condition that results in a shortage of the enzyme glucose-6-phosphate dehydrogenase, is the most common enzyme deficiency in humans. This enzyme, shown in Figure 4, is the rate-limiting enzyme for the metabolic pathway that supplies NADPH to cells (Figure 5).

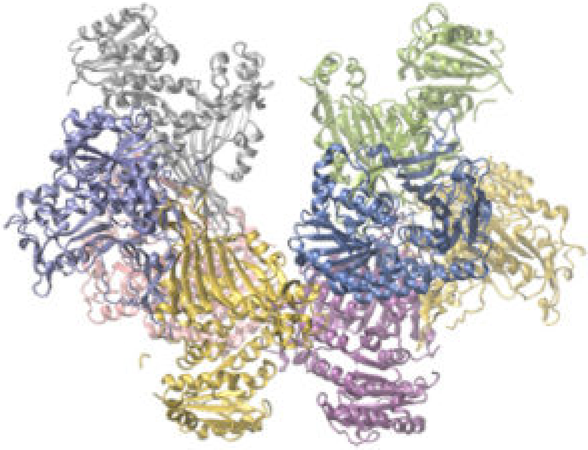


Figure 4 *Glucose-6-phosphate dehydrogenase is a rate-limiting enzyme for the metabolic pathway that supplies NADPH to cells.*

A disruption in this pathway can lead to reduced glutathione in red blood cells; once all glutathione is consumed, enzymes and other proteins such as hemoglobin are susceptible to damage. For example, hemoglobin can be metabolized to bilirubin, which leads to jaundice, a condition that can become severe. People who suffer from G6PD deficiency must avoid certain foods and medicines containing chemicals that can trigger damage their glutathione-deficient red blood cells.

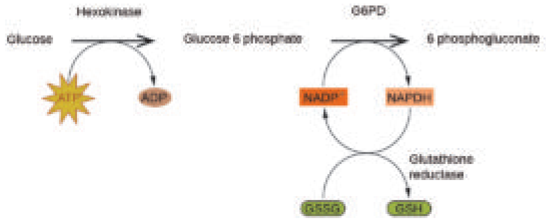


Figure 5 *In the mechanism for the pentose phosphate pathway, G6PD catalyzes the reaction that regulates NAPDH, a co-enzyme that regulates glutathione, an antioxidant that protects red blood cells and other cells from oxidative damage.*

Heterogeneous Catalysts

A heterogeneous catalyst is a catalyst that is present in a different phase (usually a solid) than the reactants. Such catalysts generally function by furnishing an active surface upon which a reaction can occur. Gas and liquid phase reactions catalyzed by heterogeneous catalysts occur on the surface of the catalyst rather than within the gas or liquid phase.

Heterogeneous catalysis has at least four steps:

- Adsorption of the reactant onto the surface of the catalyst
- Activation of the adsorbed reactant
- Reaction of the adsorbed reactant
- Diffusion of the product from the surface into the gas or liquid phase (desorption).

Any one of these steps may be slow and thus may serve as the rate determining step. In general, however, in the presence of the catalyst, the overall rate of the reaction is faster than it would be if the reactants were in the gas or liquid phase.

Figure 6 illustrates the steps that chemists believe to occur in the reaction of compounds containing a carbon–carbon double bond with hydrogen on a nickel catalyst. Nickel is the catalyst used in the hydrogenation of polyunsaturated fats and oils (which contain several carbon–carbon double bonds) to produce saturated fats and oils (which contain only carbon–carbon single bonds).

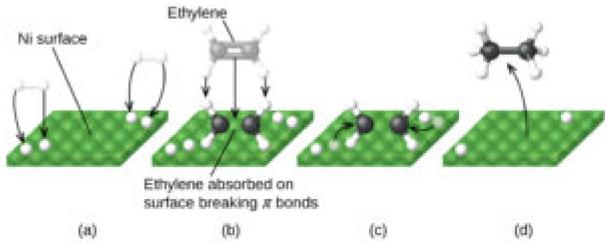


Figure 6 *There are four steps in the catalysis of the reaction* $C_2H_4+H_2 \longrightarrow C_2H_6$ *by nickel. (a) Hydrogen is adsorbed on the surface, breaking the H–H bonds and forming Ni–H bonds. (b) Ethylene is adsorbed on the surface, breaking the π-bond and forming Ni–C bonds. (c) Atoms diffuse across the surface and form new C–H bonds when they collide. (d)* C_2H_6 *molecules escape from the nickel surface, since they are not strongly attracted to nickel.*

Other significant industrial processes that involve the use of heterogeneous catalysts include the preparation of sulfuric acid, the preparation of ammonia, the oxidation of ammonia to nitric acid, and the synthesis of methanol, CH_3OH. Heterogeneous catalysts are also used in the catalytic converters found on most gasoline-powered automobiles (Figure 7).

Note: Automobile Catalytic Converters

Scientists developed catalytic converters to reduce the amount of toxic emissions produced by burning gasoline in internal combustion engines. Catalytic converters take advantage of all five factors that affect the speed of chemical reactions to ensure that exhaust emissions are as safe as possible.
By utilizing a carefully selected blend of catalytically active metals, it is possible to effect complete combustion of all carbon-containing compounds to carbon dioxide while also reducing the output of nitrogen oxides. This is particularly impressive when we consider that one step involves adding more oxygen to the molecule and the other involves removing the oxygen (Figure 7).

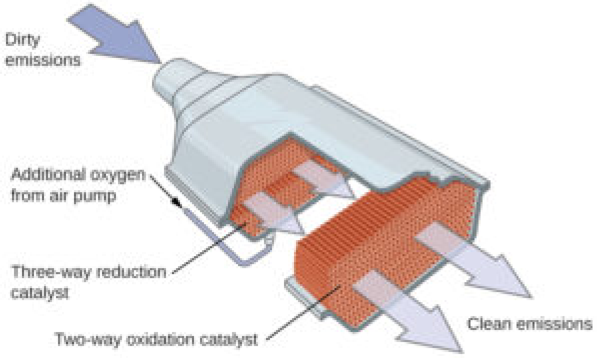


Figure 7 *A catalytic converter allows for the combustion of all carbon-containing compounds to carbon dioxide, while at the same time reducing the output of nitrogen oxide and other pollutants in emissions from gasoline-burning engines.*

Most modern, three-way catalytic converters possess a surface impregnated with a platinum-rhodium catalyst, which catalyzes the conversion nitric oxide into dinitrogen and oxygen as well as the conversion of carbon monoxide and hydrocarbons such as octane into carbon dioxide and water vapor:

$2NO_2(g) \longrightarrow N_2(g) + 2O_2(g)$

$2CO(g) + O_2(g) \longrightarrow 2CO_2(g)$

$2C_8H_{18}(g) + 25O_2(g) \longrightarrow 16CO_2(g) + 18H_2O(g)$

In order to be as efficient as possible, most catalytic converters are preheated by an electric heater. This ensures that the metals in the catalyst are fully active even before the automobile exhaust is hot enough to maintain appropriate reaction temperatures.

The University of California at Davis' "ChemWiki" provides a thorough explanation of how catalytic converters work.

Note: Enzyme Structure and Function

The study of enzymes is an important interconnection between biology and chemistry. Enzymes are usually proteins (polypeptides) that help to control the rate of chemical reactions between biologically important compounds, particularly those that are involved in cellular metabolism. Different classes of enzymes perform a variety of functions, as shown in Table 1.

Table 1 Classes of Enzymes and Their Functions

Class	Function
oxidoreductases	redox reactions
transferases	transfer of functional groups
hydrolases	hydrolysis reactions
lyases	group elimination to form double bonds
isomerases	isomerization
ligases	bond formation with ATP hydrolysis

Enzyme molecules possess an active site, a part of the molecule with a shape that allows it to bond to a specific substrate (a reactant molecule), forming an enzyme-substrate complex as a reaction intermediate. There are two models that attempt to explain how this active site works. The most simplistic model is referred to as the lock-and-key hypothesis, which suggests that the molecular shapes of the active site and substrate are complementary, fitting together like a key in a lock. The induced fit hypothesis, on the other hand, suggests that the enzyme molecule is flexible and changes shape to accommodate a bond with the substrate. This is not to suggest that an enzyme's active site is completely malleable, however. Both the lock-and-key model and the induced fit model account for the fact that enzymes can only bind with specific substrates, since in general a particular enzyme only catalyzes a particular reaction (Figure 8).

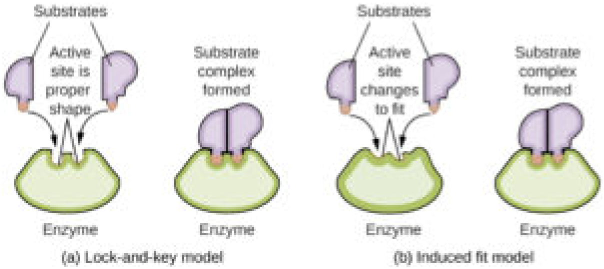


Figure 8 *(a) According to the lock-and-key model, the shape of an enzyme's active site is a perfect fit for the substrate. (b) According to the induced fit model, the active site is somewhat flexible, and can change shape in*

order to bond with the substrate.

The Royal Society of Chemistry provides an excellent introduction to enzymes for students and teachers.

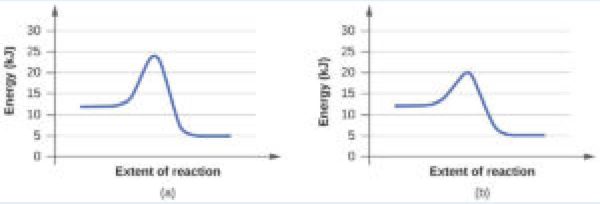
Key Concepts and Summary

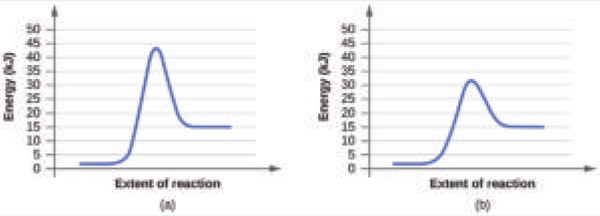
Catalysts affect the rate of a chemical reaction by altering its mechanism to provide a lower activation energy. Catalysts can be homogenous (in the same phase as the reactants) or heterogeneous (a different phase than the reactants).

Catalysis Exercises

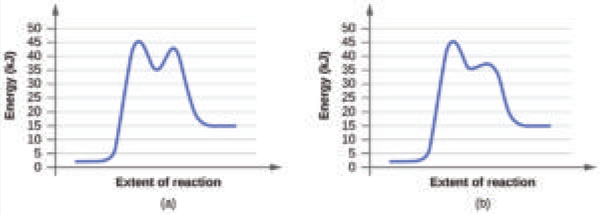
Account for the increase in reaction rate brought about by a catalyst.
Compare the functions of homogeneous and heterogeneous catalysts.
Consider this scenario and answer the following questions: Chlorine atoms resulting from decomposition of chlorofluoromethanes, such as CCl_2F_2, catalyze the decomposition of ozone in the atmosphere. One simplified mechanism for the decomposition is:
$O_3 \xrightarrow{sunlight} O_2 + O$
$O_3 + Cl \longrightarrow O_2 + ClO$
$ClO + O \longrightarrow C\ l+O_2$(a) Explain why chlorine atoms are catalysts in the gas-phase transformation:$2O_3 \longrightarrow 3O_2$(b) Nitric oxide is also involved in the decomposition of ozone by the mechanism:$O_3 \xrightarrow{sunlight} O_2 + O$
$O_3 + NO \longrightarrow NO_2 + O_2$
$NO_2 + O \longrightarrow NO + O_2$

Is NO a catalyst for the decomposition? Explain your answer.
For each of the following pairs of reaction diagrams, identify which of the pair is catalyzed:(a)

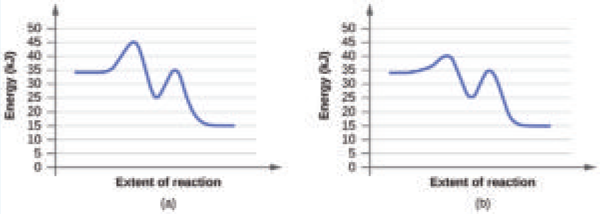




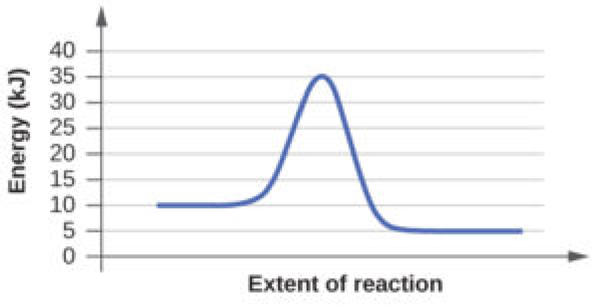
(b)
For each of the following pairs of reaction diagrams, identify which of the pairs is catalyzed:(a)



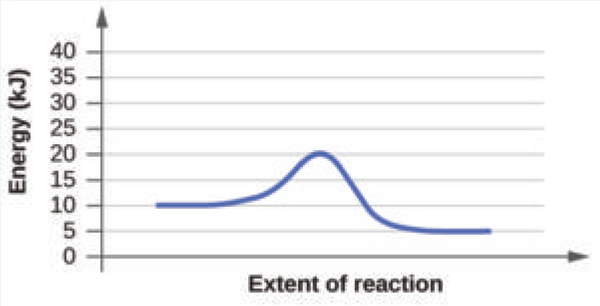
(b)



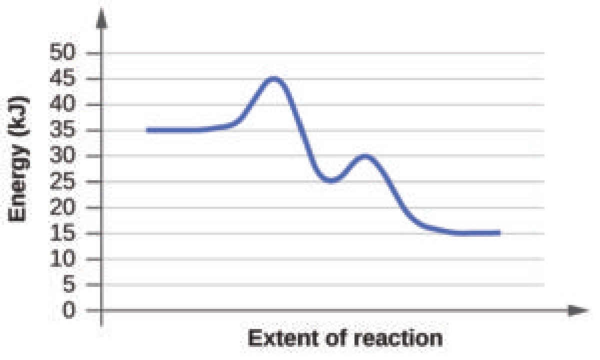
For each of the following reaction diagrams, estimate the activation energy (E_a) of the reaction:



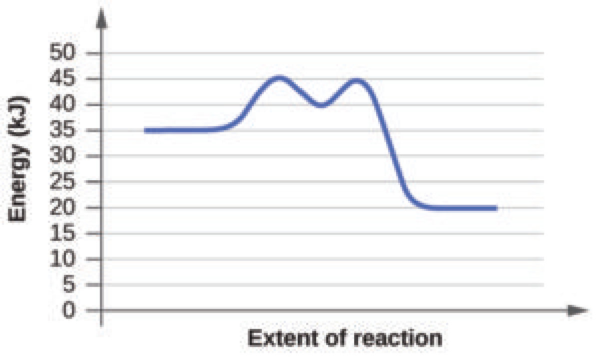
(a) (b)



For each of the following reaction diagrams, estimate the activation energy (E_a) of the reaction:



(a) (b)



Based on the diagrams in Exercise 6, which of the reactions has the fastest rate? Which has the slowest rate?
Based on the diagrams in Exercise 7, which of the reactions has the fastest rate? Which has the slowest rate?

Glossary

heterogeneous catalyst

catalyst present in a different phase from the reactants, furnishing a surface at which a reaction can occur

homogeneous catalyst

catalyst present in the same phase as the reactants

Attribution

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1 “The Nobel Prize in Chemistry 1995,” Nobel Prize.org, accessed February 18, 2015, http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1995/. ↵

47

Introduction to Leavening Agents

The word *leavening* in the baking trade is used to describe the source of gas that makes a dough or batter expand in the presence of moisture and heat. Leavening agents are available in different forms, from yeast (the organic leavener) to chemical, mechanical, and physical leaveners. Bakers choose the appropriate type of leavening based on the product they are making.

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48

Yeast

Yeast is a microscopic unicellular fungus that multiplies by budding, and under suitable conditions, causes fermentation. Cultivated yeast is widely used in the baking and distilling industries. History tells us that the early Chaldeans, Egyptians, Greeks, and Romans made leavened bread from fermented doughs. This kind of fermentation, however, was not always reliable and easy to control. It was Louis Pasteur, a French scientist who lived in the 19th century, who laid the foundation for the modern commercial production of yeast as we know it today through his research and discoveries regarding the cause and prevention of disease.

Types of Yeast

There are several types of yeast.

Wild Yeast

Wild yeast spores are found floating on dust particles in the air, in flour, on the outside of fruits, etc. Wild yeasts form spores faster than cultivated yeasts, but they are inconsistent and are not satisfactory for controlled fermentation purposes.

Compressed Yeast

Compressed yeast is made by cultivating a select variety, which is known by experiment to produce a yeast that is hardy, consistent, and produces a fermentation with strong enzymatic action. These plants are carefully isolated in a sterile environment free of any other type of yeast and cultivated on a plate containing nutrient agar or gelatin. Wort, a combination of sterilized and purified molasses or malt, nitrogenous matter, and mineral salts is used to supply the food that the growing yeast plants need to make up the bulk of compressed yeast.

After growing to maturity in the fermentation tank, the yeast is separated from the used food or wort by means of centrifugal machines. The yeast is then cooled, filtered, pressed, cut, wrapped, and refrigerated. It is marketed in 454 g (1 lb.) blocks, or in large 20 kg (45 lb.) bags for wholesale bakeries.

Figure 1 illustrates the process of cultivating compressed yeast, and Table 1 summarizes its composition.

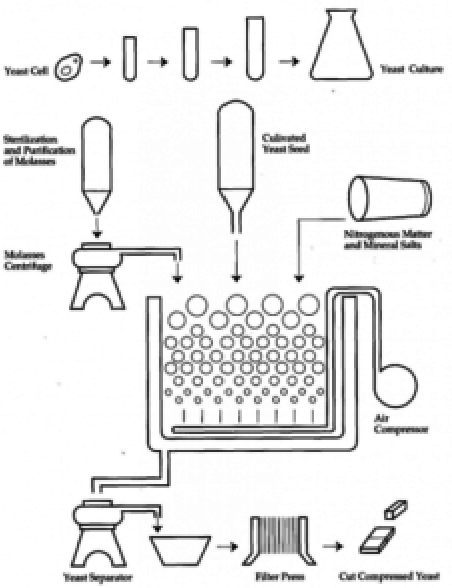

Figure 1 *Cultivating compressed yeast*

Table 1 Average composition of fresh (compressed) yeast	
Component	**Percentage**
Water	68% to 73%
Protein	12% to 14%
Fat	0.6% to 0.8%
Carbohydrate	9% to 11%
Mineral Matter	1.7% to 2%

Active Dry Yeast

Active dry yeast is made from a different strain than compressed yeast. The manufacturing process is the same except that the cultivated yeast is mixed with starch or other absorbents and dehydrated. Its production began after World War II, and it was used mainly by the armed forces, homemakers, and in areas where fresh yeast was not readily available.

Even though it is a dry product, it is alive and should be refrigerated below 7°C (45°F) in a closed container for best results. It has a moisture content of about 7%. Storage without refrigeration is satisfactory only for a limited period of time. If no refrigeration is available, the yeast should be kept unopened in a cool, dry place. It should be allowed to warm up to room temperature slowly before being used.Dry yeast must be hydrated for about 15 minutes in water at least four times its weight at a temperature between 42°C and 44°C (108°F and112°F). The temperature should never be lower than 30°C (86°F), and dry yeast should never be used before it is completely dissolved.

It takes about 550 g (20 oz.) of dry yeast to replace 1 kg (2.2 lb.) of compressed yeast, and for each kilogram of dry yeast used, an additional kilogram of water should be added to the mix. This product is hardly, if ever, used by bakers, having been superseded by instant yeast (see below).

Instant Dry Yeast

Unlike instant active dry yeast that must be dissolved in warm water for proper rehydration and activation, instant dry yeast can be added to the dough directly, either by:

- Mixing it with the flour before the water is added
- Adding it after all the ingredients have been mixed for one minute

This yeast can be reconstituted. Some manufacturers call for adding it to five times its weight of water at a temperature of 32°C to 38°C (90°F to 100°F). Most formulas suggest a 1:3 ratio when replacing compressed yeast with instant dry. Others vary slightly, with some having a 1:4 ratio. In rich Danish dough, it takes about 400 g (14 oz.), and in bread dough about 250 g to 300 g (9 oz. to 11 oz.) of instant dry yeast to replace 1 kg (2.2 lb.) of compressed yeast. As well, a little extra water is needed to make up for the moisture in compressed yeast. Precise instructions are included with the package; basically, it amounts to the difference between the weight of compressed yeast that would have been used and the amount of dry yeast used.

Instant dry yeast has a moisture content of about 5% and is packed in vacuum pouches. It has a shelf life of about one year at room temperature without any noticeable change in its gassing activity. After the seal is broken, the content turns into a granular powder, which should be refrigerated and used by its best-before date, as noted on the packaging.

Instant dry yeast is especially useful in areas where compressed yeast is not available. However, in any situation, it is practical to use and has the advantages of taking up less space and having a longer shelf life than compressed yeast.

Cream Yeast

Creamy yeast is a soft slurry-type yeast that is used only in large commercial bakeries and is pumped into the dough.

Yeast Food

Yeast food is used in bread production to condition the dough and speed up the fermentation process. It consists of a blend of mineral salts such as calcium salt or ammonium salt and potassium iodate. It has a tightening effect on the gluten and is especially beneficial in dough where soft water is used. The addition of yeast food improves the general appearance and tasting quality of bread. The retail baker does not use it much.

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49

The Functions of Yeast

Yeast has two primary functions in fermentation:

- To convert sugar into carbon dioxide gas, which lifts and aerates the dough
- To mellow and condition the gluten of the dough so that it will absorb the increasing gases evenly and hold them at the same time

In baked products, yeast increases the volume and improves the flavor, texture, grain, color, and eating quality. When yeast, water, and flour are mixed together under the right conditions, all the food required for fermentation is present as there is enough soluble protein to build new cells and enough sugar to feed them.

Activity within the yeast cells starts when enzymes in the yeast change complex sugar into invert sugar. The invert sugar is, in turn, absorbed within the yeast cell and converted into carbon dioxide gas and alcohol. Other enzymes in the yeast and flour convert soluble starch into malt sugar, which is converted again by other enzymes into fermentable sugar so that aeration goes on from this continuous production of carbon dioxide.

Proper Handling of Yeast

Compressed yeast ages and weakens gradually even when stored in the refrigerator. Fresh yeast feels moist and firm, and breaks evenly without crumbling. It has a fruity, fresh smell, which changes to a sticky mass with a cheesy odor. It is not always easy to recognize whether or not yeast has lost enough of its strength to affect the fermentation and the eventual outcome of the baked bread, but its working quality definitely depends on the storage conditions, temperature, humidity, and age.

The optimum storage temperature for yeast is -1°C (30°F). At this temperature it is still completely effective for up to two months. Yeast does not freeze at this temperature.

Other guidelines for storing yeast include:

- Rotating it properly and using the older stock first
- Avoiding overheating by spacing it on the shelves in the refrigerator

Yeast needs to breathe, since it is a living fungus. The process is continuous, proceeding slowly in the refrigerator and rapidly at the higher temperature in the shop. When respiration occurs without food, the yeast cells starve, weaken, and gradually die.

Yeast that has been frozen and thawed does not keep and should be used immediately. Freezing temperatures weaken yeast, and thawed yeast cannot be refrozen successfully.
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50

Using Yeast in Baking

Many bakers add compressed yeast directly to their dough. A more traditional way to use yeast is to dissolve it in lukewarm water before adding it to the dough. The water should never be higher than 50°C (122°F) because heat destroys yeast cells. In general, salt should not come into direct contact with yeast, as salt dehydrates the yeast. (Table 1 indicates the reaction of yeast at various temperatures.)

It is best to add the dissolved yeast to the flour when the dough is ready for mixing. In this way, the flour is used as a buffer. (Buffers are ingredients that separate or insulate ingredients, which if in too close contact, might start to react prematurely.) In sponges where little or no salt is used, yeast buds quickly and fermentation of the sponge is rapid.

Table 1 How yeast reacts at different temperatures

Temperature	**Reaction**
15°C -20°C (60°F -68°F)	slow reaction
26°C -29°C (80°F -85°F)	normal reaction
32°C -38°C (90°F -100°F)	fast reaction
59°C (138°F)	terminal death point

Never leave compressed yeast out for more than a few minutes. Remove only the amount needed from the refrigerator. Yeast lying around on workbenches at room temperature quickly deteriorates and gives poor results. One solution used by some bakeries to eliminate steps to the fridge is to have a small portable cooler in which to keep the yeast on the bench until it is needed. Yeast must be kept wrapped at all times because if it is exposed to air the edges and the corners will turn brown. This condition is known as air-burn.

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51

Introduction to Acid- bases

Figure 1 *Sinkholes such as this are the result of reactions between acidic groundwaters and basic rock formations, like limestone. (credit: modification of work by Emil Kehnel)*

In our bodies, in our homes, and in our industrial society, acids and bases play key roles. Proteins, enzymes, blood, genetic material, and other components of living matter contain both acids and bases. We seem to like the sour taste of acids; we add them to soft drinks, salad dressings, and spices. Many foods, including citrus fruits and some vegetables, contain acids. Cleaners in our homes contain acids or bases. Acids and bases play important roles in the chemical industry. Currently, approximately 36 million metric tons of sulfuric acid are produced annually in the United States alone. Huge quantities of ammonia (8 million tons), urea (10 million tons), and phosphoric acid (10 million tons) are also produced annually.

This chapter will illustrate the chemistry of acid-base reactions and equilibria, and provide you with tools for quantifying the concentrations of acids and bases in solutions.
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52

Brønsted-Lowry Acids and Bases

Acids and bases have been known for a long time. When *Robert Boyle* characterized them in 1680, he noted that acids dissolve many substances, change the color of certain natural dyes (for example, they change litmus from blue to red), and lose these characteristic properties after coming into contact with alkalis (bases). In the eighteenth century, it was recognized that acids have a sour taste, react with limestone to liberate a gaseous substance (now known to be CO_2), and interact with alkalis to form neutral substances. In 1815, *Humphry Davy* contributed greatly to the development of the modern acid-base concept by demonstrating that hydrogen is the essential constituent of acids. Around that same time, *Joseph Louis Gay-Lussac* concluded that acids are substances that can neutralize bases and that these two classes of substances can be defined only in terms of each other. The significance of hydrogen was reemphasized in 1884 when *Carl Axel Arrhenius* defined an acid as a compound that dissolves in water to yield hydrogen cations (now recognized to be hydronium ions) and a base as a compound that dissolves in water to yield hydroxide anions.

In an earlier chapter on chemical reactions, we defined acids and bases as Arrhenius did: We identified an acid as a compound that dissolves in water to yield hydronium ions (H_3O^+) and a base as a compound that dissolves in water to yield hydroxide ions ($OH^−$). This definition is not wrong; it is simply limited. Later, we extended the definition of an acid or a base using the more general definition proposed in 1923 by the Danish chemist Johannes Brønsted and the English chemist Thomas Lowry. Their definition centers on the proton, H^+. A proton is what remains when a normal hydrogen atom, ${}_1^1H$, loses an electron. A compound that donates a proton to another compound is called a *Brønsted-Lowry acid*, and a compound that accepts a proton is called a *Brønsted-Lowry base*. An acid-base reaction is the transfer of a proton from a proton donor (acid) to a proton acceptor (base). In a subsequent chapter of this text we will introduce the most general model of acid-base behavior introduced by the American chemist G. N. Lewis.

Acids may be compounds such as HCl or H_2SO_4, organic acids like acetic acid (CH_3COOH) or ascorbic acid (vitamin C), or H_2O. Anions (such as $HSO_4^−$, $H_2PO_4^−$, $HS^−$, and $HCO_3^−$) and cations (such as H_3O^+, NH_4^+, and $[Al(H_2O)_6]^{3+}$) may also act as acids. Bases fall into the same three categories. Bases may be neutral molecules (such as H_2O, NH_3, and CH_3NH_2), anions (such as $OH^−$, $HS^−$, $HCO_3^−$, $CO_3^{2−}$, $F^−$, and $PO_4^{3−}$), or cations (such as $[Al(H_2O)_5OH]^{2+}$). The most familiar bases are ionic compounds such as NaOH and $Ca(OH)_2$, which contain the hydroxide ion, $OH^−$. The hydroxide ion in these compounds accepts a proton from acids to form water:

$H^+ + OH^- \rightarrow H_2O$

We call the product that remains after an acid donates a proton the *conjugate base* of the acid. This species is a base because it can accept a proton (to re-form the acid):

acid ⇌ proton + conjugate base

$HF \rightleftharpoons H^+ + F^-$

$H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$

$H_2O \rightleftharpoons H^+ + OH^-$

$HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$

$NH_4^+ \rightleftharpoons H^+ + NH_3$

We call the product that results when a base accepts a proton the base’s *conjugate acid*. This species is an acid because it can give up a proton (and thus re-form the base):

base + proton $\rightleftharpoons$ conjugate acid

$OH^- + H^+ \rightleftharpoons H_2O$

$H_2O + H^+ \rightleftharpoons H_3O^+$

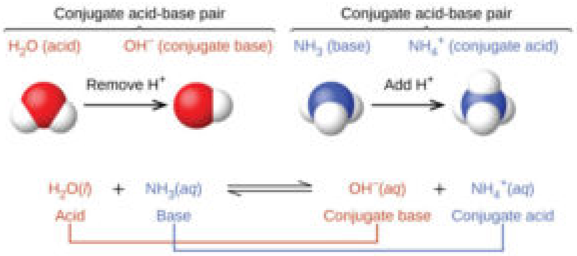
$NH_3 + H^+ \rightleftharpoons NH_4^+$

$S^{2-} + H^+ \rightleftharpoons HS^-$

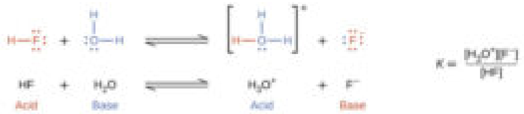
$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^-$

$F^- + H^+ \rightleftharpoons HF$

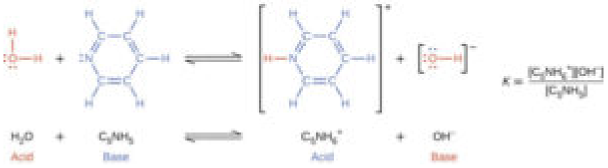
In these two sets of equations, the behaviors of acids as proton donors and bases as proton acceptors are represented in isolation. In reality, all acid-base reactions involve the *transfer* of protons between acids and bases. For example, consider the acid-base reaction that takes place when ammonia is dissolved in water. A water molecule (functioning as an acid) transfers a proton to an ammonia molecule (functioning as a base), yielding the conjugate base of water, OH^-, and the conjugate acid of ammonia, NH_4^+:



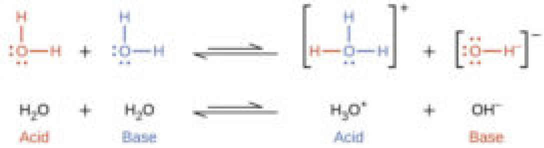
The reaction between a Brønsted-Lowry acid and water is called *acid ionization*. For example, when hydrogen fluoride dissolves in water and ionizes, protons are transferred from hydrogen fluoride molecules to water molecules, yielding hydronium ions and fluoride ions:



When we add a base to water, a *base ionization* reaction occurs in which protons are transferred from water molecules to base molecules. For example, adding ammonia to water yields hydroxide ions and ammonium ions:



Notice that both these ionization reactions are represented as equilibrium processes. The relative extent to which these acid and base ionization reactions proceed is an important topic treated in a later section of this chapter. In the preceding paragraphs we saw that water can function as either an acid or a base, depending on the nature of the solute dissolved in it. In fact, in pure water or in any aqueous solution, water acts both as an acid and a base. A very small fraction of water molecules donate protons to other water molecules to form hydronium ions and hydroxide ions:



This type of reaction, in which a substance ionizes when one molecule of the substance reacts with another molecule of the same substance, is referred to as *autoionization*.

Pure water undergoes autoionization to a very slight extent. Only about two out of every 10^9 molecules in a sample of pure water are ionized at 25 °C. The equilibrium constant for the ionization of water is called the ion-product constant for water (K_w):

$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$ $K_w = [H_3O^+][OH^-]$

The slight ionization of pure water is reflected in the small value of the equilibrium constant; at 25 °C, K_w has a value of 1.0×10^{-14}. The process is endothermic, and so the extent of ionization and the resulting concentrations of hydronium ion and hydroxide ion increase with temperature. For example, at 100 °C, the value for K_w is about 5.1×10^{-13}, roughly 100-times larger than the value at 25 °C.

Example 1: ***Ion Concentrations in Pure Water***

What are the hydronium ion concentration and the hydroxide ion concentration in pure water at 25 °C?

Solution:

The autoionization of water yields the same number of hydronium and hydroxide ions. Therefore, in pure water, $[H_3O^+] = [OH^-]$. At 25 °C:

$K_w = [H_3O^+][OH^-] = [H_3O^+]^{2+} = [OH^-]^{2+} = 1.0 \times 10^{-14}$
So:
$[H_3O^+] = [OH^-] = \sqrt{1.0 \times 10^{-14}} = 1.0 \times 10^{-7} M$
The hydronium ion concentration and the hydroxide ion concentration are the same, and we find that both equal $1.0 \times 10^{-7} M$.

Check Your Learning:

The ion product of water at 80 °C is 2.4×10^{-13}. What are the concentrations of hydronium and hydroxide ions in pure water at 80 °C?

Answer:

$[H_3O^+] = [OH^-] = 4.9 \times 10^{-7} M$

It is important to realize that the autoionization equilibrium for water is established in all aqueous solutions.

Adding an acid or base to water will not change the position of the equilibrium. Example 2 demonstrates the quantitative aspects of this relation between hydronium and hydroxide ion concentrations.

Example 2: The Inverse Proportionality of $[H_3O^+]$ and $[OH^−]$

A solution of carbon dioxide in water has a hydronium ion concentration of $2.0 \times 10^{-6} M$. What is the concentration of hydroxide ion at 25 °C?

Solution:

We know the value of the ion-product constant for water at 25 °C:

$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$ $K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$

Thus, we can calculate the missing equilibrium concentration.

Rearrangement of the K_w expression yields that $[OH^−]$ is directly proportional to the inverse of $[H_3O^+]$:

$[OH^-] = \frac{Kw}{[H_3O^+]} = \frac{1.0 \times 10^{-14}}{2.0 \times 10^{-6}} = 5.0 \times 10^{-9}$

The hydroxide ion concentration in water is reduced to $5.0 \times 10^{-9} M$ as the hydrogen ion concentration increases to $2.0 \times 10^{-6} M$. This is expected from Le Châtelier’s principle; the autoionization reaction shifts to the left to reduce the stress of the increased hydronium ion concentration and the $[OH^−]$ is reduced relative to that in pure water.

A check of these concentrations confirms that our arithmetic is correct:

$K_w = [H_3O^+][OH^-] = (2.0 \times 10^{-6})(5.0 \times 10^{-9}) = 1.0 \times 10^{-14}$

Check Your Learning:

What is the hydronium ion concentration in an aqueous solution with a hydroxide ion concentration of 0.001 *M* at 25 °C?

Answer:

$[H_3O^+] = 1 \times 10^{-11} M$

Amphiprotic Species

Like water, many molecules and ions may either gain or lose a proton under the appropriate conditions. Such species are said to be *amphiprotic*. Another term used to describe such species is *amphoteric*, which is a more general term for a species that may act either as an acid or a base by any definition (not just the Brønsted-Lowry one). Consider for example the bicarbonate ion, which may either donate or accept a proton as shown here:

$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$

$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$

Example 3: Representing the Acid-Base Behavior of an Amphoteric Substance

Write separate equations representing the reaction of $HSO_3^−$

(a) as an acid with $OH^−$
(b) as a base with HI

Solution:

(a) $HSO_3^-(aq) + OH^-(aq) \rightleftharpoons SO_3^{2-}(aq) + H_2O(l)$

(b) $HSO_3^-(aq) + HI(aq) \rightleftharpoons H_2SO_3(aq) + I^-(aq)$

Check Your Learning:

Write separate equations representing the reaction of $H_2PO_4^-$
(a) as a base with HBr

(b) as an acid with OH^-

Answer:

(a) $H_2PO_4^-(aq) + HBr(aq) \rightleftharpoons H_3PO_4(aq) + Br^-(aq)$ (b) $H_2PO_4^-(aq) + OH^-(aq) \rightleftharpoons HPO_4^{2-}(aq) + H_2O(l)$

Key Concepts and Summary

A compound that can donate a proton (a hydrogen ion) to another compound is called a Brønsted-Lowry acid. The compound that accepts the proton is called a Brønsted-Lowry base. The species remaining after a Brønsted-Lowry acid has lost a proton is the conjugate base of the acid. The species formed when a Brønsted-Lowry base gains a proton is the conjugate acid of the base. Thus, an acid-base reaction occurs when a proton is transferred from an acid to a base, with formation of the conjugate base of the reactant acid and formation of the conjugate acid of the reactant base. Amphiprotic species can act as both proton donors and proton acceptors. Water is the most important amphiprotic species. It can form both the hydronium ion, H_3O^+, and the hydroxide ion, OH^- when it undergoes autoionization:

$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

The ion product of water, K_w is the equilibrium constant for the autoionization reaction:

$K_w = [H_2O^+][OH^-] = 2.0 \times 10^{-14}$ at 25º

Key Equations

- $K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14}$ (at 25 °C)

Brønsted-Lowry Acids and Bases Exercises

Write equations that show NH_3 as both a conjugate acid and a conjugate base.
Write equations that show $H_2PO_4^-$acting both as an acid and as a base.
Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry acid:
(a) H_3O^+

(b) HCl
(c) NH_3
(d) CH_3CO_2H
(e) NH_4^+
(f) HSO_4^-

Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry acid:

(a) HNO_3
(b) PH_4^+
(c) H_2S
(d) CH_3CH_2COOH
(e) $H_2PO_4^-$
(f) HS^-

Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry base:

(a) H_2O
(b) OH^-
(c) NH_3
(d) CN^-
(e) S^{2-}
(f) $H_2PO_4^-$

Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry base:

(a) HS^-
(b) PO_4^{3-}
(c) NH_2^-
(d) C_2H_5OH
(e) O^{2-}
(f) $H_2PO_4^-$

What is the conjugate acid of each of the following? What is the conjugate base of each?

(a) OH^-
(b) H_2O
(c) HCO_3^-
(d) NH_3
(e) HSO_4^-
(f) H_2O_2
(g) HS^-
(h) $H_5N_2^+$

What is the conjugate acid of each of the following? What is the conjugate base of each?

(a) H_2S
(b) $H_2PO_4^-$
(c) PH_3
(d) HS^-
(e) HSO_3^-
(f) $H_3O_2^+$
(g) H_4N_2
(h) CH_3OH

Identify and label the Brønsted-Lowry acid, its conjugate base, the Brønsted-Lowry base, and its conjugate acid in each of the following equations:

(a) $HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$

(b) $CN^- + H_2O \rightarrow HCN + OH^-$
(c) $H_2SO_4 + Cl^- \rightarrow HCl + HSO_4^-$
(d) $HSO_4^- + OH^- \rightarrow SO_4^- + H_2O$
(e) $O^{2-} + H_2O \rightarrow 2OH^-$
(f) $[Cu(H_2O)_3(OH)]^+ + [Al(H_2O)_6]^{3+} \rightarrow [Cu(H_2O)_4]^{2+} + [Al(H_2O)_5(OH)]^{2+}$
(g) $H_2S + NH_2^- \rightarrow HS^- + NH_3$

Identify and label the Brønsted-Lowry acid, its conjugate base, the Brønsted-Lowry base, and its conjugate acid in each of the following equations:

(a) $NO_2^- + H_2O \rightarrow HNO_2 + OH^-$
(b) $HBr + H_2O \rightarrow H_3O^+ + Br^-$
(c) $HS^- + H_2O \rightarrow H_2S + OH^-$
(d) $H_2PO_4^- + OH^- \rightarrow HPO_4^{2-} + H_2O$
(e) $H_2PO_4^- + HCl \rightarrow H_3PO_4 + Cl^-$
(f) $[Fe(H_2O)_5(OH)]^{2+} + [Al(H_2O)_6]^{3+} \rightarrow [Fe(H_2O)_6]^{3+} + [Al(H_2O)_5(OH)]^{2+}$
(g) $CH_3OH + H^- \rightarrow CH_3O^- + H_2$

What are amphiprotic species? Illustrate with suitable equations.

State which of the following species are amphiprotic and write chemical equations illustrating the amphiprotic character of these species:

(a) H_2O
(b) $H_2PO_4^-$
(c) S^{2-}
(d) CO_3^{2-}
(e) HSO_4^-

State which of the following species are amphiprotic and write chemical equations illustrating the amphiprotic character of these species.

(a) NH_3
(b) HPO_4^-
(c) Br^-
(d) NH_4^+
(e) ASO_4^{3-}

Is the self ionization of water endothermic or exothermic? The ionization constant for water (K_w) is 2.9×10^{-14} at 40 °C and 9.6×10^{-14} at 60 °C.

Glossary

acid ionization

reaction involving the transfer of a proton from an acid to water, yielding hydronium ions and the conjugate base of the acid

amphiprotic

species that may either gain or lose a proton in a reaction

amphoteric

species that can act as either an acid or a base

autoionization

reaction between identical species yielding ionic products; for water, this reaction involves transfer of protons to yield hydronium and hydroxide ions

base ionization

reaction involving the transfer of a proton from water to a base, yielding hydroxide ions and the conjugate acid of the base

Brønsted-Lowry acid

proton donor

Brønsted-Lowry base

proton acceptor

conjugate acid

substance formed when a base gains a proton

conjugate base

substance formed when an acid loses a proton

ion-product constant for water (Kw)

equilibrium constant for the autoionization of water

Attribution

53

pH and pOH

As discussed earlier, hydronium and hydroxide ions are present both in pure water and in all aqueous solutions, and their concentrations are inversely proportional as determined by the ion product of water (K_w). The concentrations of these ions in a solution are often critical determinants of the solution's properties and the chemical behaviors of its other solutes, and specific vocabulary has been developed to describe these concentrations in relative terms. A solution is neutral if it contains equal concentrations of hydronium and hydroxide ions; acidic if it contains a greater concentration of hydronium ions than hydroxide ions; and basic if it contains a lesser concentration of hydronium ions than hydroxide ions.

A common means of expressing quantities, the values of which may span many orders of magnitude, is to use a logarithmic scale. One such scale that is very popular for chemical concentrations and equilibrium constants is based on the p-function, defined as shown where "X" is the quantity of interest and "log" is the base-10 logarithm:

$$pX = -\log X$$

The pH of a solution is therefore defined as shown here, where $[H_3O^+]$ is the molar concentration of hydronium ion in the solution:

$$pH = -\log [H_3O^+]$$

Rearranging this equation to isolate the hydronium ion molarity yields the equivalent expression:

$$[H_3O^+] = 10^{-pH}$$

Likewise, the hydroxide ion molarity may be expressed as a p-function, or pOH:

$$[H_3O^+] = -\log [OH^-]$$

or

$$[OH^-] = 10^{-pOH}$$

Finally, the relation between these two ion concentration expressed as p-functions is easily derived from the K_w expression:

$$K_w = [H_3O^+]\,[OH^-]$$

$$-\log K_w = -\log([H_3O^+]\,[OH^-]) = -\log [H_3O^+] + -\log [OH^-]$$

$$pK_w = pH + pOH$$

At 25 °C, the value of K_w is 1.0×10^{-14}, and so:

$14.00 = pH + pOH$

As was shown in the previous section, the hydronium ion molarity in pure water (or any neutral solution) is 1.0×10^{-7} *M* at 25 °C. The pH and pOH of a neutral solution at this temperature are therefore:

$$pH = -\log [H_3O^+] = -\log (1.0 \times 10^{-7}) = 7.00$$

$$pOH = -\log [OH^-] = -\log (1.0 \times 10^{-7}) = 7.00$$

And so, *at this temperature*, acidic solutions are those with hydronium ion molarities greater than 1.0×10^{-7} *M* and hydroxide ion molarities less than 1.0×10^{-7} *M* (corresponding to pH values less than 7.00 and pOH values greater than 7.00). Basic solutions are those with hydronium ion molarities less than 1.0×10^{-7} *M* and hydroxide ion molarities greater than 1.0×10^{-7} *M* (corresponding to pH values greater than 7.00 and pOH values less than 7.00).

Since the autoionization constant K_w is temperature dependent, these correlations between pH values and the acidic/neutral/basic adjectives will be different at temperatures other than 25 °C. For example, the "Check Your Learning" exercise in the previous section showed the hydronium molarity of pure water at 80 °C is 4.9×10^{-7} *M*, which corresponds to pH and pOH values of:

$$pH = -\log [H_3O^+] = -\log (4.9 \times 10^{-7}) = 6.31$$

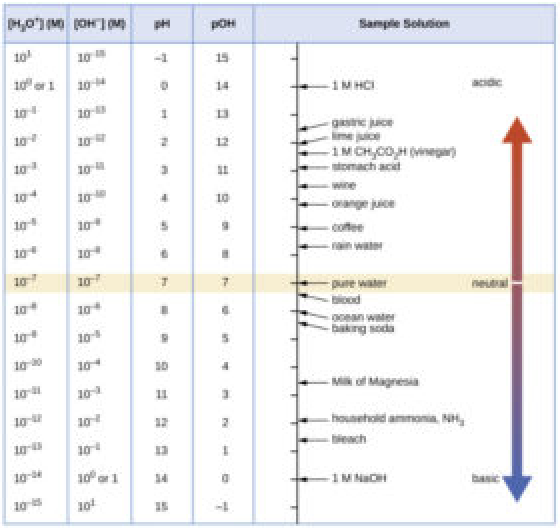
$$pOH = -\log [OH^-] = -\log (4.9 \times 10^{-7}) = 6.31$$

At this temperature, then, neutral solutions exhibit pH = pOH = 6.31, acidic solutions exhibit pH less than 6.31 and pOH greater than 6.31, whereas basic solutions exhibit pH greater than 6.31 and pOH less than 6.31. This distinction can be important when studying certain processes that occur at nonstandard temperatures, such as enzyme reactions in warm-blooded organisms. Unless otherwise noted, references to pH values are presumed to be those at standard temperature (25 °C) (Table 1).

Summary of Relations for Acidic, Basic and Neutral Solutions

Classification	Relative Ion Concentrations	pH at 25 °C
acidic	$[H_3O^+] > [OH^-]$	$pH < 7$
neutral	$[H_3O^+] = [OH^-]$	$pH = 7$
basic	$[H_3O^+] < [OH^-]$	$pH > 7$

Figure 1 shows the relationships between $[H_3O^+]$, $[OH^-]$, pH, and pOH, and gives values for these properties at standard temperatures for some common substances.



$[H_3O^+]$ (M)	$[OH^-]$ (M)	pH	pOH
10^1	10^{-15}	−1	15
10^0 or 1	10^{-14}	0	14
10^{-1}	10^{-13}	1	13
10^{-2}	10^{-12}	2	12
10^{-3}	10^{-11}	3	11
10^{-4}	10^{-10}	4	10
10^{-5}	10^{-9}	5	9
10^{-6}	10^{-8}	6	8
10^{-7}	10^{-7}	7	7
10^{-8}	10^{-6}	8	6
10^{-9}	10^{-5}	9	5
10^{-10}	10^{-4}	10	4
10^{-11}	10^{-3}	11	3
10^{-12}	10^{-2}	12	2
10^{-13}	10^{-1}	13	1
10^{-14}	10^0 or 1	14	0
10^{-15}	10^1	15	−1

Figure 1 *The pH and pOH scales represent concentrations of [H3O+] and OH−, respectively. The pH and pOH values of some common substances at standard temperature (25 °C) are shown in this chart.*

Example 1: Calculation of pH from $[H_3O^+]$

What is the pH of stomach acid, a solution of HCl with a hydronium ion concentration of 1.2×10^{-3} *M*?

Solution:

pH = -log $[H_3O^+]$

= -log(1.2×10^{-3})
= -(-2.92) = 2.92
(The use of logarithms is explained in Appendix B. Recall that, as we have done here, when taking the log of a value, keep as many decimal places in the result as there are significant figures in the value.)

Check Your Learning:

Water exposed to air contains carbonic acid, H_2CO_3, due to the reaction between carbon dioxide and water:$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$Air-saturated water has a hydronium ion concentration caused by the dissolved CO_2 of 2.0×10^{-6} *M*, about 20-times larger than that of pure water. Calculate the pH of the solution at 25 °C.

Answer:

5.70

Example 2: Calculation of Hydronium Ion Concentration from pH

Calculate the hydronium ion concentration of blood, the pH of which is 7.3 (slightly alkaline).

Solution:

$pH = -\log[H_3O^+] = 7.3$

$\log[H_3O^+] = 7.3$

$[H_3O^+] = 10^{-7.3}$ or $[H_3O^+]$ = antilog of -7.3

$[H_3O^+] = 5 \times 10^{-8}\ M$

(On a calculator take the antilog, or the “inverse” log, of −7.3, or calculate $10^{-7.3}$.)

Check Your Learning:

Calculate the hydronium ion concentration of a solution with a pH of −1.07.

Answer:

12 *M*

Note: *ENVIRONMENTAL SCIENCE*

Normal rainwater has a pH between 5 and 6 due to the presence of dissolved CO_2 which forms carbonic acid:

$H_2O(l) + CO_2(g) \rightarrow H_2CO_3(aq)$

$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$

Acid rain is rainwater that has a pH of less than 5, due to a variety of nonmetal oxides, including CO_2, SO_2, SO_3, NO, and NO_2 being dissolved in the water and reacting with it to form not only carbonic acid, but sulfuric acid and nitric acid. The formation and subsequent ionization of sulfuric acid are shown here:

$H_2O(l) + CO_2(g) \rightarrow H_2CO_3(aq)$

$H_2SO_4(aq) \rightarrow CO_2(g)\ H_2CO_3(aq)$

Carbon dioxide is naturally present in the atmosphere because we and most other organisms produce it as a waste product of metabolism. Carbon dioxide is also formed when fires release carbon stored in vegetation or when we burn wood or fossil fuels. Sulfur trioxide in the atmosphere is naturally produced by volcanic activity, but it also stems from burning fossil fuels, which have traces of sulfur, and from the process of “roasting” ores of metal sulfides in metal-refining processes. Oxides of nitrogen are formed in internal combustion engines where the high temperatures make it possible for the nitrogen and oxygen in air to chemically combine.

Acid rain is a particular problem in industrial areas where the products of combustion and smelting are released into the air without being stripped of sulfur and nitrogen oxides. In North America and Europe until the 1980s, it was responsible for the destruction of forests and freshwater lakes, when the acidity of the rain actually killed trees, damaged soil, and made lakes uninhabitable for all but the most acid-tolerant species. Acid rain also corrodes statuary and building facades that are made of marble and limestone (Figure 2). Regulations limiting the amount of sulfur and nitrogen oxides that can be released into the atmosphere by industry and automobiles have reduced the severity of acid damage to both natural and manmade environments in North America and Europe. It is now a growing problem in industrial areas of China and India.

For further information on acid rain, visit this website hosted by the US Environmental Protection Agency.

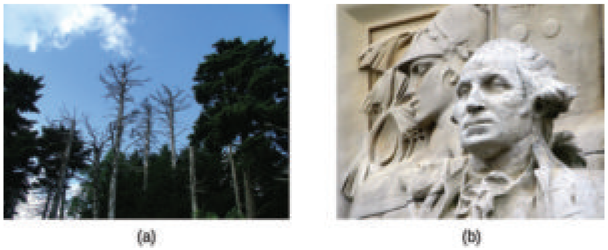

(a) (b)

Figure 2 *(a) Acid rain makes trees more susceptible to drought and insect infestation, and depletes nutrients in the soil. (b) It also is corrodes statues that are carved from marble or limestone. (credit a: modification of work by Chris M Morris; credit b: modification of work by "Eden, Janine and Jim"/Flickr)*

Example 3: Calculation of pOH

What are the pOH and the pH of a 0.0125-*M* solution of potassium hydroxide, KOH?
Solution Potassium hydroxide is a highly soluble ionic compound and completely dissociates when dissolved in dilute solution, yielding $[OH^-] = 0.0125\ M$:

$pOH = -\log[OH^-] = -\log 0.0125$
$= -(-1.903) = 1.903$
The pH can be found from the pOH:
$pH + pOH = 14.00$
$pH = 14.00 - pOH = 14.00 - 1.903 = 12.10$

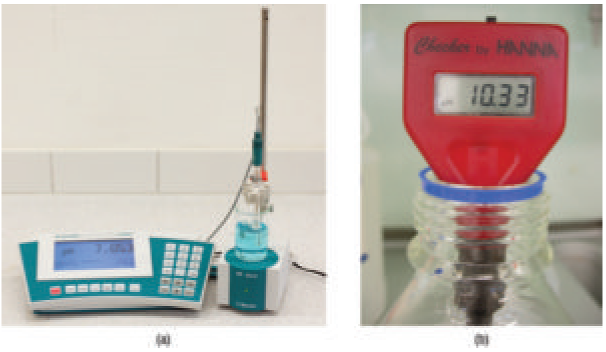
Check Your Learning:

The hydronium ion concentration of vinegar is approximately $4 \times 10^{-3}\ M$. What are the corresponding values of pOH and pH?

Answer:

pOH = 11.6, pH = 2.4

The acidity of a solution is typically assessed experimentally by measurement of its pH. The pOH of a solution is not usually measured, as it is easily calculated from an experimentally determined pH value. The pH of a solution can be directly measured using a pH meter (Figure 3).



(a) (b)

Figure 3 *(a) A research-grade pH meter used in a laboratory can have a resolution of 0.001 pH units, an accuracy of ± 0.002 pH units, and may cost in excess of $1000. (b) A portable pH meter has lower resolution (0.01 pH units), lower accuracy (± 0.2 pH units), and a far lower* *price tag. (credit b: modification of work by Jacopo Werther)*

The pH of a solution may also be visually estimated using colored indicators (Figure 4).

Figure 4 *(a) A universal indicator assumes a different color in solutions of different pH values. Thus, it can be added to a solution to determine the pH of the solution. The eight vials each contain a universal indicator and 0.1-M solutions of progressively weaker acids: HCl (pH = l), CH_3CO_2H (pH = 3), and NH_4Cl (pH = 5), deionized water, a neutral substance (pH = 7); and 0.1-M solutions of the progressively stronger bases: KCl (pH = 7), aniline, $C_6H_5NH_2$ (pH = 9), NH_3 (pH = 11), and NaOH (pH = 13). (b) pH paper contains a mixture of indicators that give different colors in solutions of differing pH values. (credit: modification of work by Sahar Atwa)*

Key Concepts and Summary

The concentration of hydronium ion in a solution of an acid in water is greater than 1.0×10^{-7} *M* at 25º C. The concentration of hydroxide ion in a solution of a base in water is greater than 1.0×10^{-7} *M* at 25º C. The concentration of H_3O^+ in a solution can be expressed as the pOH of the solution: $pOH = -\log[OH^-]$. In pure water, pH = 7.00 and pOH = 7.00

Key Equations

- $pH = -\log[H_3O^+]$
- $pOH = -\log[OH^-]$
- $[H_3O^+] = 10^{-pH}$
- $[OH^-] = 10^{-pOH}$
- $pH + pOH = pK_w = 14.00$ at 25 °C

pH and pOH Exercises

Explain why a sample of pure water at 40 °C is neutral even though $[H_3O^+] = 1.7 \times 10^{-7}$ *M*. K_w is 2.9×10^{-14} at 40 °C.

The ionization constant for water (K_w) is 2.9×10^{-14} at 40 °C. Calculate $[H_3O^+]$, $[OH^-]$, pH, and pOH for pure water at 40 °C.

The ionization constant for water (K_w) is 9.614×10^{-14} at 60 °C. Calculate $[H_3O^+]$, $[OH^-]$, pH, and pOH for pure water at 60 °C.

Calculate the pH and the pOH of each of the following solutions at 25 °C for which the

substances ionize completely:
(a) 0.200 *M* HCl
(b) 0.0143 *M* NaOH
(c) 3.0 *M* HNO_3
(d) 0.0031 *M* $Ca(OH)_2$
Calculate the pH and the pOH of each of the following solutions at 25 °C for which the substances ionize completely:
(a) 0.000259 *M* $HClO_4$
(b) 0.21 *M* NaOH
(c) 0.000071 *M* $Ba(OH)_2$
(d) 2.5 *M* KOH
What are the pH and pOH of a solution of 2.0 M HCl, which ionizes completely?
What are the pH and pOH of a solution of 2.0 M HCl, which ionizes completely?
What are the hydronium and hydroxide ion concentrations in a solution whose pH is 6.52?
Calculate the hydrogen ion concentration and the hydroxide ion concentration in wine from its pH. See Figure 1 for useful information.
Calculate the hydronium ion concentration and the hydroxide ion concentration in lime juice from its pH. See Figure 1 for useful information.
The hydronium ion concentration in a sample of rainwater is found to be 1.7×10^{-6} *M* at 25 °C. What is the concentration of hydroxide ions in the rainwater?
The hydroxide ion concentration in household ammonia is 3.2×10^{-3} *M* at 25 °C. What is the concentration of hydronium ions in the solution?

Glossary

acidic

describes a solution in which $[H_3O^+] > [OH^-]$

basic

describes a solution in which $[H_3O^+] < [OH^-]$

neutral

describes a solution in which $[H_3O^+] = [OH^-]$

pH

logarithmic measure of the concentration of hydronium ions in a solution

pOH

logarithmic measure of the concentration of hydroxide ions in a solution

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Baking Powder

Baking powder is a dependable, high-quality chemical leavener. To be effective, all baking powders rely on the reaction between one or more acids on sodium bicarbonate to produce carbon dioxide gas. Just as with yeast leavening, the presence of carbon dioxide gas creates air bubbles that cause the product to rise.

There are two main types of baking powders available on the market:

- Continuous or single-action baking powder
- Double- or multiple-action baking powder

The difference between continuous- and double-action baking powders is simply the rate of reaction:

- Continuous-action baking powder uses one acid, which continuously reacts with the soda to release gas steadily throughout the baking process until all the gassing power is spent.
- Double-action baking powder contains two different acids, which react with soda at different stages of the baking process. One acid reacts to give off a small amount of gas at low temperature, and the other major acid reacts at baking temperatures to give off the bulk of the gas.

The Leavening Mechanism of Baking Powder

Before baking, approximately 15% of the CO_2 gas is released in the cold stage. Eighty-five percent of the CO_2 gas is released in the oven starting at approximately 40°C (105°F). Some leavening power is apparently lost in the cold stage, but there is usually still adequate gassing power in the remaining portion.

When the baking powder is activated through moisture and heat, the gas works its way into the many cells created by the mixing or creaming of the batter and starts to expand them. This process comes to a halt when the starch gelatinizes and the cells become rigid. This starts at about 60°C (140°F) and is more or less complete at around 75°C (167°F). After this point, some gas may still be created, but it simply escapes through the porous structure of the product.

Using Baking Powder

For even distribution throughout the batter, baking powder should be sifted with the flour or other dry ingredients. For most cakes, about 5% baking powder to the weight of the flour produces an optimum result. Accurate scaling is important, since a little too much may cause the product to collapse. (Note this is unlike yeast, where an “overdose” will usually simply cause a more rapid rise.)
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55

Sodium Bicarbonate

When sodium bicarbonate (baking soda) is moistened and heated, it releases carbon dioxide gas. If it is moistened and heated in the presence of sufficient acid, it will release twice as much gas as if it is moistened and heated without the presence of an acid.

Slightly acidic ingredients provide the mix with some of the necessary acids for the release of carbon dioxide gas. Examples are:

- Honey
- Molasses
- Ginger
- Cocoa
- Bran

For this reason, some of the mixes contain baking powder only while others contain a combination of baking powder and baking soda. If an excessive amount of baking soda is used in a cake batter without the presence of sufficient acid, the normally white cake crumb will have a yellowish-brown color and a strong undesirable smell of soda.

The gas evolves very fast at the beginning of baking when the **pH** level is still on the acidic side (pH of around 5 to 6). Once the soda neutralizes the acid, the dough or batter quickly becomes **alkaline** and the release of gas is reduced. Mixes and doughs leavened with baking soda must be handled without delay, or the release of the gas may be almost exhausted before the product reaches the oven.

The darker color of the crumb found on the bottom half of a cake or muffins is caused by the partial dehydration of the batter that is heated first during baking. In spiced honey cookies and gingerbread, baking soda is used alone to give them quick color during baking and yet keep the products soft.

In chocolate cakes, baking soda is used in conjunction with baking powder to keep the pH at a desirable level. However, it is important to know whether the cocoa powder you are using is natural or treated by the Dutch process. In the Dutch process, some of the acid in the cocoa is already neutralized, and there is less left for the release of gas in the mix. This means more baking powder and less baking soda is used.

Baking soda in a chocolate mix not only counteracts the acid content in the baked cake but also improves the grain and color of the cake. A darker and richer chocolate color is produced if the acid level is sufficient to release all the carbon dioxide gas. On the other hand, the reddish, coarse, open-grained crumb in devil’s food cake is the result of using baking soda as the principal leavening agent.

The level of baking soda depends on the nature of the product and on the other ingredients in the formula. Cookies, for example, with high levels of fat and sugar, do not require much, if any, leavening.

Table 1 provides the recommended amounts of baking soda for different products. Note that the percentages appear small compared to the 5% level of baking powder suggested because baking powder contains both an acid agent and a leavening agent.

Table 1 Recommended amounts of baking soda

Product	**Amount of Baking Soda (% of flour weight)**
Cookies	0.4-0.6

Cakes	0.5-1.0
Cake doughnuts	0.7-1.0
Pancakes	1.4-2.0

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56

Ammonium Bicarbonate

Ammonium bicarbonate is a white crystalline powder used in flat, spiced cookies, such as gingerbreads, and in eclair paste. It must be dissolved in the cold liquid portion of the batter. At room temperature, decomposition of CO_2 in the batter is minimal. When heated to approximately 60°C (140°F) decomposition is more noticeable, and at oven temperature, decomposition takes place in a very short time. Ammonium bicarbonate should only be used in low moisture-containing products that are not dense. Providing that these conditions are met, there will be no taste and odor remaining from the ammonium.

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57

Water Hardness and pH

Effects on Baking

Most municipal supplies of water contain chlorine, which is used to ensure the purity of the water. Some cities add fluoride to their water supply to stop tooth decay. Neither chlorine nor fluoride is present in large enough quantities to affect dough in any way. In addition, most municipal water is treated to reduce excessive acidity, since this could be corrosive for the water lines. It is therefore unlikely that bakers using municipal water need to be concerned about extremely acidic water.

Soft water is another matter, as it can lead to sticky dough. An addition of yeast food, or a reduction in dough water, will help. Alkaline water tends to tighten the dough and retard fermentation, since enzymes work best in slightly acidic dough.

If there is a possibility of water problems, a sample should be forwarded to a laboratory for a complete analysis.
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Understanding Ingredients: Dairy Products

Introduction to Dairy Products

Milk and milk products are some of our oldest and best-known natural foods. In baking, milk is used fresh, condensed, powdered, skimmed, or whole. The great bulk, weight, and perishability of fresh milk plus the expense of refrigeration makes it a relatively high-cost ingredient, and for this reason, most modern bakeries use non-fat powdered milk or buttermilk powder.

Over the past 20 years, there has been a trend to lower fat content in dairy products. This reflects the high caloric value of milk fat, and also is compatible with the trend to leaner, healthier nutrition. These “low-fat” products often have the fat replaced with sugars, so care must be taking in substituting these ingredients in a recipe. For bakers, this trend has not meant any great changes in formulas: a 35% milk fat or a 15% cream cheese product usually works equally well in a cheesecake. Some pastry chefs find lowering the richness in pastries and plated desserts can make them more enjoyable, especially after a large meal.

Table 1 provides the nutritional properties of milk products.

Table 1 Nutritional properties of milk products (per 100 g)

	Whole Milk (3.5% milk fat)	**Skim Milk (0.1% milk fat)**	**Coffee Cream (18% milk fat)**	**Heavy or Whipping Cream (36% milk fat)**
Protein	3.22 g	3.37 g	3 g	2 g
Fat	3.25 g	0.08 g	19 g	37 g
Cholesterol	10 mg	2 mg	66 mg	137 mg
Potassium	143 mg	156 mg	122 mg	75 mg
Calcium	113 mg	125 mg	96 mg	65 mg
Magnesium	10 mg	11 mg	9 mg	7 mg
Sodium	40 mg	42 mg	40 mg	40 mg
Vitamin A (IU)	102 IU	204 IU	656 IU	1470 IU

Note: Besides the elements shown in Table 1, all dairy products contain vitamin B-complex.

IU = International Units, a term used in nutritional measurement
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59

Milk

Homogenized milk is fresh milk in which the fat particles are so finely divided and emulsified mechanically that the milk fat cannot separate on standing. The milk fat is forced into tiny droplets. As soon as the droplets form, milk proteins and emulsifiers form a protective film around each one, preventing the fat from reuniting. The tiny droplets stay suspended indefinitely, and milk fat no longer separates and rises to the top as a cream layer. In other words, homogenized dairy products are stable emulsions of fat droplets suspended in milk. It is also said that homogenized milk is more readily digestible.

Pasteurization of milk was developed in 1859 by the French chemist Louis Pasteur. One method of pasteurization is to heat milk to above 71°C (160°F), maintain it at this temperature for a set time, then cool it immediately to 10°C (50°F) or lower. This kills all harmful bacteria that carry the potential threat of bovine tuberculosis and fever from cows to humans.

The two main types of pasteurization used today are high-temperature, short-time (HTST, also known as “flash”) and higher-heat, shorter time (HHST). Ultra-high-temperature (UHT) processing is also used.

- High-temperature, short-time (HTST) pasteurization is done by heating milk to 72°C (161°F) for 15 seconds. Milk simply labelled “pasteurized” is usually treated with the HTST method.
- Higher-heat, shorter time (HHST) milk and milk products are pasteurized by applying heat continuously, generally above 100°C (212°F) for such time to extend the shelf life of the product under refrigerated conditions. This type of heat process can be used to produce dairy products with extended shelf life (ESL).
- Ultra-high-temperature (UHT) processing holds the milk at a temperature of 140°C (284°F) for four seconds. During UHT processing, milk is sterilized rather than pasteurized. This process allows milk or juice to be stored several months without refrigeration. The process is achieved by spraying the milk or juice through a nozzle into a chamber that is filled with high-temperature steam under pressure. After the temperature reaches 140°C (284°F) the fluid is cooled instantly in a vacuum chamber and packed in a pre-sterilized, airtight container. Milk labelled UHT has been treated in this way.

For more information on pasteurization, visit the International Dairy Foods Association.
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60

Milk Products ADD US

Cream

The usual minimum standard for cream is 10% fat content, though it ranges between 10% and 18%. Cream in this range may be sold as half and half, coffee cream, or table cream.

Whipping cream is about 32% to 36% in milk fat content. Cream with 36% or higher is called heavy cream. This percentage of fat is not a mandated standard; much less than this and the cream simply will not whip. For best whipping results, the cream should be 48 to 60 hours old and be cold. A stabilizer, some sugar, and flavour may be added during whipping. Before adding stabilizer, check the ingredients on the carton; some whipping creams nowadays have added agents such as carrageenan, in which case an additional stabilizer may not be necessary.

Canadian cream definitions are similar to those used in the United States, except for that of "light cream." In Canada, what the U.S. calls light cream is referred to most commonly as half and half. In Canada, "light cream" is low-fat cream, usually with 5% to 6% fat. You can make your own light cream by blending milk with half-and-half.

In Quebec, country cream is sold, which contains 15% milk fat. If you are using a recipe that calls for country cream, you may substitute 18% cream.

If you have recipes from the UK, you might see references to *double cream*. This is cream with about 48% milk fat, which is not readily available in Canada, except in some specialty stores. Use whipping cream or heavy cream instead.

Table 1 lists some of the common cream types and their uses.

Table 1 Cream types and fat content

Name	**Minimum Milk Fat**	**Additional Definition**	**Main Uses**
Whipping cream	32%	Heavy cream has at least 36% milk fat	Whips well, can be piped; custards, cream fillings, confectionary products
Table cream	18%	Coffee cream	Added to coffee, poured over puddings, used in sauces
Half-and-half	10%-12%	Cereal cream	Added to coffee; custards and ice cream mixes
Light cream	5%-10%		Added to coffee

Buttermilk

There are two methods to produce buttermilk:

- Inoculating milk with a specific culture to sour it
- Churning milk and separating the liquid left over from the butter

The second method is where buttermilk gets its name, but today, most of what is commonly called buttermilk is the first type. Buttermilk has a higher acid content than regular milk (pH of 4.6 compared with milk's pH of 6.6).

The fermented dairy product known as *cultured buttermilk* is produced from cow's milk and has a characteristically sour taste caused by lactic acid bacteria. This variant is made using one of two species of bacteria — either *Lactococcus lactis* or *Lactobacillus bulgaricus*, which creates more tartness in certain recipes.

The acid in buttermilk reacts with the sodium bicarbonate (baking soda) to produce carbon dioxide, which acts as the leavening agent.

Sour Cream

Sour cream is made from cream soured by adding lactic acids and thickened naturally or by processing. Milk fat content may vary from 5.5% to 14%. The lactic acid causes the proteins in sour cream to coagulate to a gelled consistency; gums and starches may be added to further thicken it. The added gums and starches also keep the liquid whey in sour cream from separating.

Use sour cream in cheesecakes, coffee cakes, and pastry doughs. Low-fat and fat-free sour cream are available. Low-fat sour cream, which is essentially cultured half-and-half or light cream (and usually contains 7% to 10% milk fat), is often satisfactory as a substitute for regular sour cream in baking. These products are higher in moisture and less rich in flavor than regular sour cream.

Crème Fraîche

Crème fraîche (fresh cream) is a soured cream containing 30% to 45% milk fat and having a pH of around 4.5. It is soured with bacterial culture. Traditionally it is made by setting unpasteurized milk into a pan at room temperature, allowing the cream to rise to the top. After about 12 hours, the cream is skimmed off. During that time, natural bacteria in the unpasteurized milk ripens the cream, turning it into a mildly sour, thickened product.

An effective substitute can be made by adding a small amount of cultured buttermilk or sour cream to whipping cream and allowing it to stand in a warm spot for 10 hours or more before refrigerating. As the cream ripens from the growth of the lactic acid bacteria, it thickens and develops a sour flavour. This product is similar to sour cream, but it has a higher milk fat content.

Milk Substitutes

Milk substitutes are becoming increasingly popular as replacements for straight skim milk powders. Innumerable replacement blends are available to the baker. Their protein contents range from 11% to 40%; some are wet, some are dry-blended. Product types vary from all dairy to mostly cereal. All-dairy blends range from mostly dry skim milk to mostly whey. A popular blend is whey mixed with 40% soy flour solids and a small quantity of sodium hydroxide to neutralize the whey acidity.

Dough consistency may be a little softer if the milk in the replacement blend exceeds 3%, and this could dictate the need to increase dough mixing by at least half a minute. However, absorption and formula changes are seldom necessary when switching from dry milk to a blend, or from a blend to a blend.

For nutritional labelling, or when using a blend in a non-standardized product that must carry an itemized ingredient label, all blend components must be listed in their proper order on the label.

The Canadian Food Inspection Agency defines modified milk ingredients as any of the following in liquid, concentrated, dry, frozen, or reconstituted form:

- Calcium-reduced skim milk
- Casein: This a protein in milk and is used as a binding agent. Caseins are also used in wax to shine fruits and vegetables, as an adhesive, and to fortify bread. Caseins contain common amino acids.
- Caseinate: This protein is derived from skim milk. Bodybuilders sometimes take powder enriched

with calcium caseinate because it releases proteins at an even, measured pace.
- Cultured milk products: These are milk products that have been altered through controlled fermentation, including yogurt, sour cream, and cultured buttermilk.
- Milk serum proteins
- Ultra-filtered milk: The Canadian Food and Drug Regulations define this type of milk as that which "has been subjected to a process in which it is passed over one or more semi-permeable membranes to partially remove water, lactose, minerals, and water-soluble vitamins without altering the whey protein-to-casein ratio and that results in a liquid product."
- Whey: This is serum by-product created in the manufacture of cheese.
- Whey butter: Typically oily in composition, whey butter is made from cream separated from whey.
- Whey cream: This is cream skimmed from whey, sometimes used as a substitute for sweet cream and butter.
- Any component of milk that has been altered from the form in which it is found in milk.

Milk Powder

Milk powder is available in several different forms: whole milk, skim milk (non-fat dry milk), buttermilk, or whey. They are all processed similarly: the product is first pasteurized, then concentrated with an evaporator, and finally dried (spray or roller dried) to produce powder.

- Whole milk powder must contain no less than 95% milk solids and must not exceed 5% moisture. The milk fat content must be no less than 2.6%. Vitamins A and D may be added and the emulsifying agent lecithin may also be added in an amount not exceeding 0.5%.
- Skim milk powder (non-fat dry milk) must contain no less than 95% milk solids and must not exceed 4% moisture or 1.5% fat.
- Buttermilk powder must contain no less than 95% milk solids and must not exceed 3% moisture or 6% fat.
- Whey powder consists primarily of carbohydrate (lactose), protein (several different whey proteins, mainly lactalbumins and globulins), various minerals, and vitamins. Whey powder is a valuable addition to the functional properties of various foods as well as a source of valuable nutrients because it contains approximately 50% of the nutrients in the original milk.

Table 2 compares the composition of milk and two powdered milk products.

Table 2 Comparison of fresh and powdered milk products (% by weights)

	Whole Milk	**Skim Milk Powder (Non-fat dry milk)**	**Buttermilk Powder**
Milk fat	3.25	0.7	5.0
Protein	3.5	36.0	34.0
Milk sugar (lactose)	4.9	51.0	48.0
Minerals	0.8	8.2	7.9
Water	87.0	3.0	3.0
Calcium	0.12	1.3	1.3

- To make 10 L (22 lb.) of liquid skim milk from skim milk powder, 9.1 L (2.4 gal.) of water and 900 g (2 lb.) of skim milk powder are required.
- To make 10 L (22 lb.) of whole milk from skim milk powder, 8.65 L (2.25 gal) of water, 900 g (2 lb.) of skim milk powder, and 450 g (1 lb.) of butter are needed.

When reconstituting dried milk, add it to the water and whisk in immediately. Delaying this, or adding water to the milk powder, will usually result in clogging. Water temperature should be around 21°C (70°F).

Evaporated Milk

Sometimes called concentrated milk, this includes evaporated whole, evaporated partly skimmed, and evaporated skim milks, depending on the type of milk used in its production. Canadian standards require 25% milk solids and 7.5% milk fat.

All types of evaporated milk have a darker color than the original milk because at high temperatures a browning reaction occurs between the milk protein and the lactose. After 60% of the water is removed by evaporation, the milk is homogenized, cooled, restandardized, and canned. It is then sterilized by heating for 10 to 15 minutes at 99°C to 120°C (210°F to 248°F). Controlled amounts of disodium phosphate and/or sodium citrate preserve the “salt balance” and prevent coagulation of the milk that might occur at high temperatures and during storage.

Sweetened Condensed Milk

Sweetened condensed milk is a viscous, sweet-colored milk made by condensing milk to one-third of its original volume, which then has sugar added. It contains about 40% sugar, a minimum of 8.5% milk fat, and not less than 28% total milk solids.
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Milk in bread baking

In the dough stage, milk increases water absorption. Consequently, dough made with milk should come softer from the mixer than dough made with water. Other aspects of milk in yeast doughs include:

- Dough may be mixed more intensively.
- Milk yields dough with a higher pH compared to water dough, and the fermentation will be slower.
- Fermentation tolerance (the ability of the dough to work properly in a range of temperatures) will be slightly improved.
- Bench time will be extended as the dough ferments more slowly at this stage. (Final proof times will be about the same, as by this time the yeast has adjusted to the condition of the dough.)

Bread made with milk will color faster in the oven and allowance should be made for this. If taken out too early after a superficial examination of crust color, it may collapse slightly and be hard to slice. The loaf should be expected to have a darker crust color than bread made without milk.

In the finished product, milk will make bread that has:

- Greater volume (improved capacity to retain gas)
- Darker crust (due to the lactose in the milk)
- Longer shelf life (due partly to the milk fat)
- Finer and more “cottony” grain
- Better slicing due to the finer grain

If skim milk or skim milk powder is used, some of the above benefits will not be so evident (e.g., longer shelf life, which is a result of the fat in the milk).

The type of sugar found in milk, lactose, has little sweetening power and does not ferment, so in dough made with skim milk powder, sugar has to be added or the fermentation will be very slow. While lactose is not fermentable, it caramelizes readily in the oven and produces a healthy crust color. The recommended amount of skim milk powder used in fermented dough is 2% to 8% based on flour, and up 15% in cakes.

Buttermilk and sour milk are used to make variety breads. They have a lower pH and require a shorter fermentation for good results.
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62

Yogurt

Yogurt is a thick or semi-solid food made from pasteurized milk fermented by lactic bacteria. The milk coagulates when a sufficient quantity of lactic acid is produced. Yogurt is a rich, versatile food capable of enhancing the flavor and texture of many recipes. It is prepared sweetened or unsweetened, and is used in baking to make yogurt-flavored cream cakes, desserts, and frozen products.

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63

Lactose

This milk sugar is a complex sugar (see sugar section). It is available commercially spray-dried and in crystalline form. There are many advantages to using it in various baking applications:

- Because of its low sweetening value compared to sucrose, it can lend texture and create browning while keeping the sweetness level at low values, which many consumers prefer. It can be used to replace sucrose up to a 50% level, or replace it entirely in products like pie pastry.
- Lactose improves dough handling properties and the color of the loaf.
- In pie crusts, it gives good color to top and bottom crusts, more tender crusts, and retards sogginess.
- In machine-dropped cookies, lactose can help the dough release better from the die.
- In cakes and muffins, it gives body without excessive sweetening and improves volume.
- Lactose binds flavors that are normally volatile and thus intensifies or enhances flavor.

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64

Cheese

Cheese is a concentrated dairy product made from fluid milk and is defined as the fresh or matured product obtained by draining the whey after coagulation of casein.

Cheese making consists of four steps:

Curdling of the milk, either by enzyme (rennet) or by lactic curdling (natural process)
Draining in which the whey (liquid part) is drained from the curd (firm part)
Pressing, which determines the shape
Ripening, in which the rind forms and the curd develops flavor

Cheese can be classified, with some exceptions, into five broad categories, as follows. Examples are given of specific cheeses that may be used in baking.

Fresh cheese: High moisture content and no ripening characterize these products. Examples: cottage cheese, baker's cheese, cream cheese, quark, and ricotta.
Soft cheeses: Usually some rind, but with a soft interior. Example: feta.
Semi-soft cheeses: Unripened cheeses of various moisture content. Example: mozzarella.
Firm cheeses: Well-ripened cheese with relatively low moisture content and fairly high fat content. Examples: Swiss, cheddar, brick.
Hard cheeses: Lengthy aging and very low moisture content. Example: Parmesan.

In baking, cheeses have different functions. Soft cheeses, mixed with other ingredients, are used in fillings for pastries and coffeecakes. They are used for certain European deep-fried goods, such as cannoli. They may also be used, sometimes in combination with a richer cream cheese, for cheesecakes. All the cheeses itemized under fresh cheese (see above) are all more or less interchangeable for these functions. The coarser cheese may be strained first if necessary. The firmer cheeses are used in products like cheese bread, quiches, pizza, and cheese straws.

A brief description of the cheeses most likely to be used by bakers follows.

Dry Curd Cottage Cheese

This is a soft, unripened, acid cheese. Pasteurized skim milk is inoculated with lactic-acid-producing bacteria, and a milk-clotting enzyme (rennet) is added. Following incubation, the milk starts to clot, and it is then cut into cubes. After gentle cooking, the cubes or curds become quite firm. At this point, the whey is drained off, and the curd is washed and cooled with cold water.

Creamed Cottage Cheese

Creamed or dressed cottage cheese consists of dry curd cottage cheese combined with a cream dressing. The milk fat content of the dressing determines whether the final product is "regular" (4% milk fat) or low fat (1% to 2% milk fat).

Baker's Cheese

This is a soft, unripened, uncooked cheese. It is made following exactly the same process as for dry curd cottage cheese, up to and including the point when the milk clot is cut into cubes. This cheese is not cooked to remove the whey from the curd. Rather, the curd is drained through cloth bags or it may be pumped through a curd concentrator. The product is then ready to be packaged. The milk fat content is generally about 4%.

Quark

Quark (or quarg) is a fresh unripened cheese prepared in a fashion similar to cottage cheese. The mild flavor and smooth texture of quark make it excellent as a topping or filling for a variety of dishes. Quark is similar to baker's cheese, except acid is added to it (it is inoculated with lactic-acid-producing bacteria), and then it is blended with straight cream to produce a smooth spread containing approximately 7% milk fat. Today there are low-fat quarks with lower percentage, and high-fat versions with milk fat adjusted to 18%. Quark cheese can often be used in place of sour cream, cottage cheese, or ricotta cheese.

Cream Cheese

Cream cheese is a soft, unripened, acid cheese. A milk-and-cream mixture is homogenized and pasteurized, cooled to about 27°C (80°F), and inoculated with lactic-acid-producing bacteria. The resulting curd is not cut, but it is stirred until it is smooth, and then heated to about 50°C (122°F) for one hour. The curd is drained through cloth bags or run through a curd concentrator. Regular cream cheese is fairly high fat, but much lighter versions exist now.

Ricotta

Ricotta is a fresh cheese prepared from either milk or whey that has been heated with an acidulating agent added. Traditionally lemon juice or vinegar was used for acidulation, but in commercial production, a bacterial culture is used. The curds are then strained and the ricotta is used for both sweet and savory applications.

Mascarpone

Mascarpone is a rich, fresh cheese that is a relative of both cream cheese and ricotta cheese. Mascarpone is prepared in a similar fashion to ricotta, but using cream instead of whole milk. The cream is acidified (often by the direct addition of tartaric acid) and heated to a temperature of 85°C (185°F), which results in precipitation of the curd. The curd is then separated from the whey by filtration or mechanical means. The cheese is lightly salted and usually whipped. Note that starter culture and rennet are not used in the production of this type of cheese. The high-fat content and smooth texture of mascarpone cheese make it suitable as a substitute for cream or butter. Ingredient applications of mascarpone cheese tend to focus on desserts. The most famous application of mascarpone cheese is in the Italian dessert tiramisu.

Table 1 provides the composition of various types of cheeses.

Table 1 Composition of various cheeses (% by weight)

	Moisture %	**Milk Fat %**	**Salt %**
Dry curd cottage cheese	80	0.4	n/a
Regular creamed cottage cheese	79	4	1
Low fat (1% and 2%) creamed cottage cheese	79	1-2	1
Baker's cheese	79	4	1
Quark	72	5-7	n/a
Quark (high fat)	59	18	n/a
Cream cheese	54 (varies)	17- 37	1
Ricotta	72-75	8-13	n/a

Mascarpone	46	60-75	1

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Understanding Ingredients: Eggs

Eggs Grade (ADD US)

Fresh hen eggs are sold by grade in all provinces. All shell eggs that are imported, exported, or shipped from one province to another for commercial sale must be graded. In Canada, it is mandatory to have all eggs graded by the standards set by Agriculture and Agri-Foods Canada (AAFC). The grade name appears on cartons. The grades Canada A and Canada B bear the maple leaf symbol with the grade name inside, and Canada C and Nest Run eggs will have the grade name printed in block text. The grades indicate the quality of the egg and should not be confused with size. Only Canada A are available in different sizes. The average large size egg weighs about 56 g (2 oz.) as indicated in Table 1.

Table 1 Canada Grade A egg sizes

Size	**Weight (including shell)**
Peewee	Less than 42 g (1.5 oz.)
Small	At least 42 g (1.5 oz.)
Medium	At least 49 g (1.75 oz.)
Large	At least 56 g (2 oz.)
Extra Large	At least 63 g (2.25 oz.)
Jumbo	70 g (2.5 oz.) or more

The Canada grade symbol does not guarantee that the eggs are of Canadian origin, but it does guarantee that the products meet Canadian government standards. Agriculture Canada inspects all egg-processing plants to ensure that the products are wholesome and processed according to sanitary standards. The pasteurization of “packaged” egg product is also monitored.

The criteria for grading eggs are:

- Weight
- Cleanliness
- Soundness and shape of shell
- Shape and relative position of yolk within the egg
- Size of air cell free of abnormalities
- Freedom from dissolved yolk and blood spots

Canada A

Canada A eggs are clean, normal in shape with sound shells, and have the finest interior quality. They are ideal for all uses. The yolks are round and compact and surrounded by very thick, firm albumen. Canada A eggs are a premium quality and in limited supply on the retail market. If eggs are not sold within a limited time, unsold stocks are returned to the supplier. Eggs graded as A must meet the minimum weight for the declared size (see Table 12.) The size designation for Canada A eggs must appear on the label.

Canada B

Canada B eggs have very slight abnormalities. This grade is fine for baking, where appearance is not important. These eggs must weigh at least 49 g (1.75 oz.). There are no size designations on the label for Canada B eggs.

Canada C

Canada C is considered a processing grade and provides a safe outlet for the disposition of cracked eggs. Canada C eggs must be shipped to a federally registered processed egg station and pasteurized as a means of controlling the higher risk of salmonella or other microbial contamination that may be found in cracked eggs.

These eggs are suitable for processing into commercially frozen, liquid, and dried egg products. Sizes are not specified.

Canada Nest Run

Since Canada Nest Run eggs are generally sent for further processing, they are usually not washed, candled (a process discussed later in this chapter), or sized. However, nest run eggs must meet the minimum quality requirements prescribed by the egg regulations. This grade, as with other Canada grades, can only be applied to eggs in a federally registered egg station.

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66

Composition and Nutrition

Table 1 Composition of eggs by percent of weight. Traces of sugar and ash are also present.

	Composition of Eggs (%) Whole Egg	**Composition of Eggs (%) Yolk**	**Composition of Eggs (%) White**
Moisture	73.0	49.0	86.0
Protein	13.3	16.7	11.6
Lipid	11.5	31.6	0.2

Table 2 Nutritional content of a large egg

	Whole Egg	**Yolk**	**White**
Weight	50 g	17 g	33 g
Protein	6 g	3 g	3 g
Fat	5 g	5 g	Trace
Cholesterol	216 mg	216 mg	0
Calcium	25 mg	2 mg	27 mg
Iron	1.0 mg	0.6 mg	Trace
Sodium	63 mg	7 mg	54 mg
Potassium	60 mg	16 mg	47 mg
Vitamin A	96 RE	99 RE	0 RE

Note: B-complex vitamins, not itemized, are well represented in eggs, as are amino acids. RE = retinol equivalent, a term used in nutritional measurement.

Worth noting is the concentration of certain food elements in different parts of the egg. Note for example that all the cholesterol is in the yolk. The yolk is relatively rich in iron and the white is high in calcium.

In practice, when separating large eggs, one estimates the weight of the white as 30 g (1 oz) and the yolk as 20 g (0.7 oz). The color of the shell, which is either a creamy white or brown, is relevant to the breed of the hen, and there is no other basic difference in the content of the egg or the shell.

The color of the yolk depends on the diet of the hens. Bakers have a preference for eggs with dark yolks. Certainly the appearance of cakes made with such eggs is richer. Tests have found that, although eggs with darker yolks tend to produce moister sponge cakes, the cakes are somewhat coarser and less tender.
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67

Egg Products

A number of egg products besides whole shell eggs are used in the baking and food service industry. By law, all egg products other than shell eggs are pasteurized to protect them against salmonella, and the low temperature at which they are kept inhibits bacterial activity, although under certain conditions they may spoil very rapidly.

The chief categories of egg products available are:

- Liquid eggs (whole eggs and whole eggs with additional yolks)
- Frozen eggs (whole eggs, egg whites, and egg yolks)
- Dried and powdered eggs (whole eggs, egg whites, and meringue powder)

Liquid and Frozen Eggs

Liquid and frozen whole eggs are preferred in large bakeries where cracking and emptying of shells is not economical. They are also one of the most economical ways of purchasing eggs. Liquid and frozen whole eggs are sometimes “fortified” by the addition of egg yolks. Some bakers feel that liquid or frozen eggs don’t yield the same volume in sponge cakes as fresh eggs, and there is a certain bias in favor of shell eggs.

If stored in the freezer at -18°C (0°F) or lower, liquid and frozen eggs will keep for long periods with minimum loss of quality. Thawing should take place in the refrigerator or under cold water without submerging the container. Leaving frozen eggs at room temperature to thaw is a bad practice because the outside layers of egg can reach a temperature favorable to bacteria while the centre is still frozen. Heat should never be used to defrost eggs. Unused portions must be refrigerated and used within 24 hours.

Frozen egg yolks consist of 90% egg yolks and 10% sugar to prevent the yolk from gelling and to avoid separation of the fat.

Spray-Dried Whole Eggs and Egg Whites

Dried eggs are used by some bakers as a convenience and cost saver. As with frozen eggs, some bakers doubt their performance in products such as sponge cakes. But dried eggs produce satisfactory results because of the addition of a carbohydrate to the egg before the drying process, usually corn syrup, which results in foaming comparable to fresh eggs.

Dried whole eggs should be stored unopened in a cool place not over 10°C (50°F), preferably in the refrigerator. They are reconstituted by blending 1 kg (2.2 lb.) of powdered whole egg with 3 kg (6.6 lb) of cold water. The water is added slowly while mixing. Once reconstituted, dried eggs should be used immediately or refrigerated promptly and used within an hour.

In mixes such as muffins and cake doughnuts, dried eggs can be mixed in with the other dry ingredients and do not have to be reconstituted. In layer cake formulas, dried eggs are blended with the other dry ingredients before the fat and some water are added, followed by the balance of liquid in two stages.

Spray-dried egg whites are reconstituted by mixing 1 kg (2.2 lb.) of powdered egg white with 1 kg (2.2 lb.) of cold water, letting it stand for 15 minutes, and then adding 9 kg (20 lb.) of cold water. When used in cake mixes, the powdered egg white is blended with the other dry ingredients, but only 7 L (7 qt.) of cold water is used for every 1 kg (2.2 lb.) of powdered egg white.

Dry Egg Substitutes or Replacements

Egg substitutes are made from sweet cheese, whey, egg whites, dextrose, modified tapioca starch, **sodium** caseinate, and artificial color and flavor. They are cost-cutters and can be used alone or in combination with fresh or dried eggs in cakes, cookies, and fillings. One kg (2.2 lb.) of powder is mixed with 4 kg (9 lb.) of water to replace powdered eggs.

Meringue Powder

While it is not a pure dehydrated egg white, meringue powder is widely used by bakers to make baked Alaska, royal icing, and toppings. It contains vegetable gums and starches to absorb moisture and make it whip better.

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68

The Function of Eggs

Eggs are a truly multifunctional ingredient and have many roles to play in the bakeshop. Their versatility means that product formulas may be adjusted once the properties of eggs are understood. For example, in French butter cream, egg whites may be substituted in the summer for whole eggs to give a more stable and bacteria-free product (egg white is alkaline, with pH 8.5). A yolk or two may be worked into a sweet short paste dough to improve its extensibility. Sponge cake formulas can be adjusted, for example, with the addition of egg yolks in jelly rolls to improve rolling up.

If a recipe is changed by replacing some or all of the eggs with water, two factors must be remembered:

> Water replacement is about 75% of the egg content, since egg solids constitute about 25% of the egg.
> Leavening ability is lessened and must be made up by the addition of chemical leavening.

Other uses of eggs are:

- Leavening: They will support many times their own weight of other ingredients through their ability to form a cell structure either alone or in combination with flour. The egg white in particular is capable of forming a large mass of cells by building a fine protein network.
- Moistening and binding: The fat in eggs provides a moistening effect, and the proteins present coagulate when heated, binding ingredients together.
- Thickening: Eggs are valuable thickeners in the cooking of chiffon pie fillings and custard.
- Emulsifying: Lecithin, present in the yolk, is a natural emulsifier and assists in making smooth batters.
- Customer appeal: Eggs enhance the appearance of products through their colour and flavour, and they improve texture and grain.
- Structure: Eggs bind with other ingredients, primarily flour, creating the supporting structure for other ingredients.
- Shelf life: The shelf life of eggs is extended through the fat content of the yolk.
- Nutrition: Eggs are a valuable food in every respect. Note, however, that 4% of the lipid in egg yolk is cholesterol, which may be a concern to some people. Developments in poultry feed claim to have reduced or eliminated this cholesterol level.
- Tenderizing: The fat in eggs acts like a shortening and improves the tenderness of the baked cake.

Keep these points in mind when using eggs:

- Spots in eggs are due to blood fragments in the ovary. Such eggs are edible and may be used.
- The albumen or egg white is soluble in cold water, congeals at 70°C (158°F), and remains insoluble from then on.
- Cover leftover yolks or whites tightly and refrigerate. Add a little water on top of yolks, or mix in 10% sugar, to prevent crusting. Do not return unused portions to the master container.
- Use clean utensils to dip egg products from their containers.

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69

Storing Eggs

Whole eggs are the perfect medium for the development of bacteria and mould. Eggs with an undesirable odor may be high in bacteria or mould. While some of these odors disappear in baking, some will remain and give an off-taste to the product if the odor is concentrated and strong.

Store fresh eggs in the refrigerator in cartons to prevent moisture loss and absorption of odours. If refrigerator space is at a premium, eggs are stable for up to three weeks if kept at a temperature of 13°C to 15°C (55°F to 60°F). Naturally, this must be in a location with invariable conditions.

Food poisoning can result from using eggs held too long before using. Liquid or cracked eggs should be kept under refrigeration at all times.

Whole eggs can be checked for freshness with the candling or salt water method:

- Candling method: Hold the egg up to a light in a darkened room or positioned so that the content or condition of the egg may be seen. If the yolk is held firmly by the white when the egg is turned, and the egg is clean and not broken, then the egg is of good quality. Smell or odor is not readily revealed unless the shell is broken.
- Salt water method: Add 100 g of salt to 1 L (3.5 oz. to 1 qt.) of water. Allow to dissolve completely. When an egg is placed in this mixture, its level of buoyancy determines the age of the egg. An old egg will float to the surface, while a fresher egg will sink to the bottom.

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Chocolate

70

From the Cocoa Bean to the Finished Chocolate

In North America, chocolate manufacturing started in Massachusetts in 1765. Today, in the factory, the beans get cleaned, and magnets take out metallic parts, and then sand, dust, and other impurities are removed. Some starch will be changed into dextrins in the roasting process to improve flavor. Machines break the beans and grind them fine until a flowing liquid is produced, called chocolate liquor. Through hydraulic pressure, cocoa butter is reduced from 55% to approximately 10% to 24% or less, and the residue forms a solid mass called *press cake.*

The press cake is then broken, pulverized, cooled, and sifted to produce commercial cocoa powder. The baking industry uses primarily cocoa powders with a low fat content.

At the factory, chocolate is also subject to an additional refining step called **conching.** Conching has a smoothing effect. The temperature range in this process is between 55°C and 65°C (131°F and 149°F). Sugar interacts with protein to form amino sugars, and the paste loses **acids** and moisture and becomes smoother.

This video explains the chemical reactions related to heat, melting point, and formation of crystal structures in chocolate: http://science360.gov/obj/video/27d931d9-c33c-45c6-adac-aa0a42f04ad6/chemistry-chocolate
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71

Chocolate Produced for the Baking Industry

True chocolate contains cocoa butter. The main types of chocolate, in decreasing order of cocoa liquor content, are:

- Unsweetened (bitter) chocolate
- Dark chocolate
- Milk chocolate
- White chocolate

Unsweetened Chocolate

Unsweetened chocolate, also known as bitter chocolate, baking chocolate, or cooking chocolate, is pure cocoa liquor mixed with some form of fat to produce a solid substance. The pure ground, roasted cocoa beans impart a strong, deep chocolate flavor. With the addition of sugar in recipes, however, it is used as the base for cakes, brownies, confections, and cookies.

Dark (Sweet, Semi-Sweet, Bittersweet) Chocolate

Dark chocolate has an ideal balance of cocoa liquor, cocoa butter, and sugar. Thus it has the attractive, rich color and flavor so typical of chocolate, and is also sweet enough to be palatable. It does not contain any milk solids. It can be eaten as is or used in baking. Its flavor does not get lost or overwhelmed, as in many cases when milk chocolate is used. It can be used for fillings, for which more flavorful chocolates with high cocoa percentages ranging from 60% to 99% are often used. *Dark* is synonymous with semi-sweet, and *extra dark* with bittersweet, although the ratio of cocoa butter to solids may vary.

- Sweet chocolate has more sugar, sometimes almost equal to cocoa liquor and butter amounts (45% to 55% range).
- Semi-sweet chocolate is frequently used for cooking. It is a dark chocolate with less sugar than sweet chocolate.
- Bittersweet chocolate has less sugar and more liquor than semi-sweet chocolate, but the two are often interchangeable when baking. Bittersweet and semi-sweet chocolates are sometimes referred to as *couverture* (see below). The higher the percentage of cocoa, the less sweet the chocolate is.

Milk Chocolate

Milk chocolate is solid chocolate made with milk, added in the form of milk powder. Milk chocolate contains a higher percentage of fat (the milk contributes to this) and the melting point is slightly lower. It is used mainly as a flavoring and in the production of candies and moulded pieces.

White Chocolate

The main ingredient in white chocolate is sugar, closely followed by cocoa butter and milk powder. It has no cocoa liquor. It is used mainly as a flavoring in desserts, in the production of candies and, in chunk form in cookies.

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72

Couverture

The usual term for top quality chocolate is **couverture**. Couverture chocolate is a very high-quality chocolate that contains extra cocoa butter. The higher percentage of cocoa butter, combined with proper tempering, gives the chocolate more sheen, firmer “snap” when broken, and a creamy mellow flavor. Dark, milk, and white chocolate can all be made as couvertures.

The total percentage cited on many brands of chocolate is based on some combination of cocoa butter in relation to cocoa liquor. In order to be labelled as couverture by European Union regulations, the product must contain not less than 35% total dry cocoa solids, including not less than 31% cocoa butter and not less than 2.5% of dry non-fat cocoa solids. Couverture is used by professionals for dipping, coating, moulding, and garnishing.

What the percentages don’t tell you is the proportion of cocoa butter to cocoa solids. You can, however, refer to the nutrition label or company information to find the amounts of each. All things being equal, the chocolate with the higher fat content will be the one with more cocoa butter, which contributes to both flavor and mouthfeel. This will also typically be the more expensive chocolate, because cocoa butter is more valuable than cocoa liquor.

But keep in mind that just because two chocolates from different manufacturers have the same percentages, they are not necessarily equal. They could have dramatically differing amounts of cocoa butter and liquor, and dissimilar flavors, and substituting one for the other can have negative effects for your recipe. Determining the amounts of cocoa butter and cocoa liquor will allow you to make informed decisions on chocolate choices.
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73

Definitions and Regulations (ADD US)

The legislation for cocoa and chocolate products in Canada is found in Division 4 of the Food and Drug Regulations (FDR), under the Food and Drugs Act (FDA). The Canadian Food Inspection Agency (CFIA) is responsible for administering and enforcing the FDR and FDA. Here are some of the regulations governing cocoa and chocolate:

- Cocoa butter must be the only fat source. Chocolate sold in Canada cannot contain vegetable fats or oils.
- Chocolate must contain chocolate liquor.
- The only sweetening agents permitted in chocolate in Canada are listed in Division 18 of the Food and Drug Regulations.
- Artificial sweeteners such as aspartame, sucralose, acesulfame potassium, and sugar alcohols (sorbitol, maltitol, etc.) are not permitted.
- Milk and/or milk ingredients are permissible.
- Emulsifying agents are permissible, as are flavors such as vanilla.

Cocoa butter and sugar quantities are not defined in the regulations. Some semi-sweet chocolate may be sweeter than so-called sweet chocolate. And remember that bittersweet chocolate is not, as you might expect, sugarless. Only if the label states “unsweetened,” do you know that there is no sugar added.

Products manufactured or imported into Canada that contain non-permitted ingredients (vegetable fats or oils, artificial sweeteners) cannot legally be called chocolate when sold in Canada. A non-standardized name such as “candy” must be used.

Finally, lecithin, which is the most common emulsifying agent added to chocolate, is approved for use in chocolate in North America and Europe, but Canadian regulations state that no more than 1% can be added during the manufacturing process of chocolate. Emulsifiers like lecithin can help thin out melted chocolate so it flows evenly and smoothly. Because it is less expensive than cocoa butter at thinning chocolate, it can be used to help lower the cost. The lecithin used in chocolate is mainly derived from soy. Both GMO (**genetically modified** organism) and non-GMO soy lecithin are available. Check the manufacturer’s packaging and ingredient listing for the source of soy lecithin in your chocolate.
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Understanding Ingredients: Spices

Elements of Taste

Essentially there are a handful of elements that compose all of the taste profiles found in the foods we eat. Western definitions of taste conventionally define four major elements of taste:

- Salty
- Sweet
- Sour
- Bitter

Asian cultures have added the following to the list:

- Umami (literally “pleasant savory taste”)
- Spiciness
- Astringency

Foods and recipes that contain a number of these elements in balance are generally those that we think of as tasting good.
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75

Introduction to Salt

Historically, salt was a prestigious commodity. “The salt of the earth” describes an outstanding person. The word *salary* comes from the Latin *salaria,* which was the payment made to Roman soldiers for the purchase of salt. In Arabic, the phrase translated as “there is salt between us” expresses the covenant between humans and the divine. Though no longer a valuable commodity in the monetary sense, salt is still valuable in the sense of being crucial to human health.

Salt can be found deposited in Earth’s layers in rock salt deposits. These deposits formed when the water in the oceans that covered Earth many millions of years ago evaporated. The salt was then covered by various types of rocks.

Common salt (sodium chloride) is 40% sodium and 60% chloride. An average adult consumes about 7 kg (15 lb.) per year.

Today, we have three basic methods of obtaining salt from natural sources:

Mining rock salt
Extracting salt from salt brines created by pumping water into underground salt deposits
Evaporating salt water from oceans, seas, and salt lakes

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76

Types of Salt

Mined Rock Salt

In some countries, salt is mined from salt beds approximately 150 m to 300 m (490 ft. to 985 ft.) below Earth's surface. Sometimes, impurities such as clay make it impossible to use rock salt without purification. Purification makes it possible to get the desired flavor and color, thus making it edible. Edible salt is highly refined: pure and snow white.

Salt from Salt Brines

Salt can also be mined from natural salt beds by using water to extract the salt in the form of a brine, which saves having to construct a mine. Holes are drilled approximately 20 cm (8 in.) in diameter until the salt deposits are reached. A pipe is then driven into the salt beds and another pipe is driven inside the larger pipe further into the deposits. Pressurized water is forced through the outer pipe into the salt beds, and then pumped back out through the smaller pipe to the refineries. Through separation of the impurities, eventually all water in the brine will evaporate, leaving crystallized salt, which then can be dried, sifted, and graded in different sizes.

Ocean, Sea, and Lake Salt

In some countries, especially those with dry and warm climates, salt is recovered straight from the ocean or salt lakes. The salt water is collected in large shallow ponds (also called *salt gardens*) where, through the heat of the sun, the water slowly evaporates. Moving the salt solution from one pond to another until the salt crystals become clear and the water has evaporated eliminates impurities. The salt is then purified, dried completely, crushed, sifted, and graded.

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77

Functions of Salt in Baking

Salt has three major functions in baking. It affects:

- Fermentation
- Dough conditioning
- Flavor

Fermentation

Fermentation is salt's major function:

- Salt slows the rate of fermentation, acting as a healthy check on yeast development.
- Salt prevents the development of any objectionable bacterial action or wild types of fermentation.
- Salt assists in oven browning by controlling the fermentation and therefore lessening the destruction of sugar.
- Salt checks the development of any undesirable or excessive acidity in the dough. It thus protects against undesirable action in the dough and effects the necessary healthy fermentation required to secure a finished product of high quality.

Dough Conditioning

Salt has a binding or strengthening effect on gluten and thereby adds strength to any flour. The additional firmness imparted to the gluten by the salt enables it to hold the water and gas better, and allows the dough to expand without tearing. This influence becomes particularly important when soft water is used for dough mixing and where immature flour must be used. Under both conditions, incorporating a maximum amount of salt will help prevent soft and sticky dough. Although salt has no direct bleaching effect, its action results in a fine-grained loaf of superior texture. This combination of finer grain and thin cell walls gives the crumb of the loaf a whiter appearance.

Flavour

One of the important functions of salt is its ability to improve the taste and flavor of all the foods in which it is used. Salt is one ingredient that makes bread taste so good. Without salt in the dough batch, the resulting bread would be flat and insipid. The extra palatability brought about by the presence of salt is only partly due to the actual taste of the salt itself. Salt has the peculiar ability to intensify the flavor created in bread as a result of yeast action on the other ingredients in the loaf. It brings out the characteristic taste and flavor of bread and, indeed, of all foods. Improved palatability in turn promotes the digestibility of food, so it can be said that salt enhances the nutritive value of bakery products. The lack of salt or too much of it is the first thing noticed when tasting bread. In some bread 2% can produce a decidedly salty taste, while in others the same amount gives a good taste. The difference is often due to the mineralization of the water used in the dough.
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78

Using Salt in Fermented Doughs

The average amount of salt to use in dough is about 1.75% to 2.25% based on the flour used. Some authorities recommend that the amount of salt used should be based on the actual quantity of water used in making the dough, namely about 30 g per L (1 oz. per qt.) of water.

During the hot summer months, many bakers find it advantageous to use slightly more salt than in the winter as a safeguard against the development of any undesirable changes in the dough fermentation. Salt should never be dissolved in the same water in which yeast is dissolved. It is an antiseptic and dehydrates yeast cells and can even kill part of them, which means that less power is in the dough and a longer fermentation is needed. In bread made by the sponge dough method and in liquid fermentation systems, a small amount of salt included in the first stage strengthens the gluten.
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79

Storing Salt

Salt is very stable and does not spoil under ordinary conditions. However, it may have a slight tendency to absorb moisture and become somewhat lumpy and hard. Therefore, it is advisable to store it in a clean, cool, and dry place. Inasmuch as salt can absorb odors, the storage room should be free from any odor that might be taken up and carried by the salt.

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Introduction to Spices and Other Flavorings

Food touches all of the senses. We taste, we smell, we see color and shape, we feel texture and temperature, and we hear sounds as we eat.

All of these elements together create a palette with an infinite number of combinations, but the underlying principles that make food taste good are unchanged.

- Variety and diversity in textures and the elements of taste make for interesting food.
- Contrast is as important as harmony; but avoid extremes and imbalance.

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81

Seasoning and Flavoring

Many ingredients are used to enhance the taste of foods. These ingredients can be used to provide both seasoning and flavoring.

- *Seasoning* means to bring out or intensify the natural flavor of the food without changing it. Seasonings are usually added near the end of the cooking period. The most common seasonings are salt, pepper, and acids (such as lemon juice). When seasonings are used properly, they cannot be tasted; their job is to heighten the flavors of the original ingredients.
- *Flavoring* refers to something that changes or modifies the original flavor of the food. Flavoring can be used to contrast a taste such as adding liqueur to a dessert where both the added flavor and the original flavor are perceptible. Or flavorings can be used to create a unique flavor in which it is difficult to discern what the separate flavorings are. Spice blends used in pumpkin pies are a good example of this.

Knowing how to use seasonings and flavorings skillfully provides cooks and bakers with an arsenal with which they can create limitless flavor combinations.

Flavoring and seasoning ingredients include wines, spirits, fruit zests, extracts, essences, and oils. However, the main seasoning and flavoring ingredients are classified as herbs and spices.

Knowing the difference between herbs and spices is not as important as knowing how to use seasonings and flavorings skillfully. In general, fresh seasonings are added late in the cooking process while dry ones tend to be added earlier. It is good practice to under-season during the cooking process and then add more seasonings (particularly if you are using fresh ones) just before presentation. This is sometimes referred to as “layering.” When baking, it is difficult to add more seasoning at the end, so testing recipes to ensure the proper amount of spice is included is a critical process.
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82

Herbs

Herbs tend to be the leaves of fragrant plants that do not have a woody stem. Herbs are available fresh or dried, with fresh herbs having a more subtle flavor than dried. You need to add a larger quantity of fresh herbs (up to 50% more) than dry herbs to get the same desired flavor. Conversely, if a recipe calls for a certain amount of fresh herb, you would use about one-half of that amount of dry herb.

The most common fresh herbs are basil, coriander, marjoram, oregano, parsley, rosemary, sage, tarragon, and thyme. Fresh herbs should have a clean, fresh fragrance and be free of wilted or brown leaves. They can be kept for about five days if sealed inside an airtight plastic bag. Fresh herbs are usually added near the completion of the cooking process so flavors are not lost due to heat exposure.

Dried herbs lose their power rather quickly if not properly stored in airtight containers. They can last up to six months if properly stored. Dried herbs are usually added at the start of the cooking process as their flavor takes longer to develop than fresh herbs.
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83

Spices

Spices are aromatic substances obtained from the dried parts of plants such as the roots, shoots, fruits, bark, and leaves. They are sold as seeds, blends of spices, whole or ground spices, and seasonings. The aromatic substances that give a spice its particular aroma and flavor are the essential oils. The flavor of the essential oil or flavoring compound will vary depending on the quality and freshness of the spice.

The aromas of ground spices are volatile. This means they lose their odor or flavoring when left exposed to the air for extended periods. They should be stored in sealed containers when not in use. Whole beans or unground seeds have a longer shelf life but should also be stored in sealed containers.

Allspice

Allspice is only one spice, yet it has a flavor resembling a blend of cloves, nutmeg, and cinnamon. At harvest time, the mature (but still green) berries from the allspice trees (a small tropical evergreen) are dried in the sun. During drying they turn reddish-brown and become small berries. The berries are about 0.6 cm (1/4 in.) in diameter and contain dark brown seeds.

Allspice is grown principally in Jamaica and to a lesser degree in Mexico. Allspice is available whole or ground. Bakers usually use ground allspice in cakes, cookies, spices, and pies.

Anise

Anise is the small, green-grey fruit or seed of a plant of the parsley family. The plant grows to a height of 45 cm (18 in.) and has fine leaves with clusters of small white flowers. It is native to Mexico and Spain, with the latter being the principal producer. Anise seeds are added to pastries, breads, cookies, and candies.

Caraway

Caraway is the dried fruit or seed of a biennial plant of the parsley family, harvested every second year, primarily in the Netherlands. It is also produced in Poland and Russia. The many-branched, hollow-stemmed herb grows up to 60 cm (24 in.) high and has small white flowers. Caraway is a small crescent-shaped brown seed with a pleasant aroma but somewhat sharp taste. Although it is most familiar in rye bread, caraway is also used in cookies and cakes.

Cardamom

Native to India, Sri Lanka, and Guatemala, cardamom is the fruit or seed of a plant of the ginger family. The three-sided, creamy-white, flavorless pod holds the tiny aromatic, dark brown seeds. It is available in whole and ground (pod removed). Cardamom in ground form flavors Danish pastries and coffee cakes, Christmas baking, and Easter baking such as hot cross buns.

Cinnamon

Cinnamon comes from the bark of an aromatic evergreen tree. It is native to China, Indonesia, and Indochina. Cinnamon may be purchased in ground form or as cinnamon sticks. Ground cinnamon is used in pastries, breads, puddings, cakes, candy, and cookies. Cinnamon sticks are used for preserved fruits and flavoring puddings. Cinnamon sugar is made with approximately 50 g (2 oz.) of cinnamon to 1 kg (2.2 lb.) of granulated sugar.

Cassia

Cassia, sometimes known as Chinese cinnamon, is native to Assam and Myanmar. It is similar to cinnamon but a little darker with a sharper taste. It is considered better for savory rather than sweet foods. It is prized in Germany and some other countries as a flavor in chocolate.

Cloves

Cloves are the dried, unopened buds of a tropical evergreen tree, native to Indonesia. The flavor is characterized by a sweet, pungent spiciness. The nail-shaped whole cloves are mainly used in cooking, but the ground version of this spice heightens the flavor of mincemeat, baked goods, fruit pies, and plum pudding.

Ginger

Ginger is one of the few spices that grow below the ground. It is native to southern Asia but is now imported from Jamaica, India, and Africa. The part of the ginger plant used is obtained from the root. Ground ginger is the most commonly used form in baking — in fruitcakes, cookies, fruit pies, and gingerbread. Candied ginger is used in pastries and confectionery.

Mace

Originating in the East and West Indies, mace is the fleshy growth between the nutmeg shell and outer husk, yellow-orange in color. It is usually sold ground, but sometimes whole mace (blades of mace) is available. Mace is used in pound cakes, breads, puddings, and pastries.

Nutmeg

Nutmeg is the kernel or seed of the nutmeg fruit. The fruit is similar to the peach. The fleshy husk, grooved on one side, splits, releasing the deep-brown aromatic nutmeg. It is available whole or ground. Ground nutmeg is used extensively in custards, cream puddings, spice cakes, gingerbread, and doughnuts.

Poppy Seed

Poppy seed comes from the Netherlands and Asia. The minute, blue-grey, kidney-shaped seeds are so small they seem to be round. Poppy seeds are used in breads and rolls, cakes and cookies, and fillings for pastries.

Sesame or Benne Seed

Sesame or benne seeds are the seeds of the fruit of a tropical annual herb grown in India, China, and Turkey. The seeds are tiny, shiny, and creamy-white with a rich almond-like flavor and aroma. Bakers use sesame seeds in breads, buns, coffee cakes, and cookies.

Vanilla

The Spaniards named vanilla. The word derives from *vaina*, meaning pod. Vanilla is produced from an orchid-type plant native to Central America. The vanilla beans are cured by a complicated process, which helps explain the high cost of genuine vanilla. The cured pods should be black in color and packed in airtight boxes. Imitation vanilla extracts are made from a colorless crystalline synthetic compound called vanillin. Pure vanilla extract is superior to imitation vanilla. Artificial vanilla is more intense than real vanilla by a factor of 3 to 4 and must be used sparingly.

To use vanilla beans, split the pod down the middle to scrape out the seeds. The seeds are the flavoring agents. Alternatively, the split pod can be simmered in the milk or cream used in dessert preparation. Its flavoring power is not spent in one cooking and it can be drained, kept frozen, and reused. A vanilla bean kept in a container of icing sugar imparts the flavor to the sugar, all ready for use in cookies and cakes.

Vanilla extract is volatile at temperatures starting at 138°C (280°F) and is therefore not ideal for flat products such as cookies. It is suitable for cakes, where the interior temperature does not get so high.

Vanilla beans and vanilla extract are used extensively by bakers to flavor a wide range of desserts and other items.
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84

Flavorings in Baking

Flavors cannot be considered a truly basic ingredient in bakery products but are important in producing the most desirable products. Flavoring materials consist of:

- Extracts or essences
- Emulsions
- Aromas
- Spices

Note: Salt may also be classed as a flavoring material because it intensifies other flavors.

These and others (such as chocolate) enable the baker to produce a wide variety of attractively flavored pastries, cakes, and other bakery products. Flavor extracts, essences, emulsions, and aromas are all solutions of flavor mixed with a solvent, often ethyl alcohol.

The flavors used to make extracts and essences are the extracted essential oils from fruits, herbs, and vegetables, or an imitation of the same. Many fruit flavors are obtained from the natural parts (e.g., rind of lemons and oranges or the exterior fruit pulp of apricots and peaches). In some cases, artificial flavor is added to enhance the taste, and artificial coloring may be added for eye appeal. Both the Canadian and U.S. departments that regulate food restrict these and other additives. The flavors are sometimes encapsulated in corn syrup and emulsifiers. They may also be coated with gum to preserve the flavor compounds and give longer shelf life to the product. Some of the most popular essences are compounded from both natural and artificial sources. These essences have the true taste of the natural flavors.

Aromas are flavors that have an oil extract base. They are usually much more expensive than alcoholic extracts but purer and finer in their aromatic composition. Aromas are used for flavoring delicate creams, sauces, and ice creams.

Emulsions are homogenized mixtures of aromatic oils and water plus a stabilizing agent (e.g., vegetable gum). Emulsions are more concentrated than extracts and are less susceptible to losing their flavor in the oven. They can therefore be used more sparingly.
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