Swiss Cheese Fondue: Chemistry in the Kitchen

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Abstract: Cheese making and fondue making are among the earliest applications of chemistry to biotechnology. The history and chemistry of dairy products, cheese making, and fondue are discussed, and detailed directions for preparation of Swiss cheese fondue are given.

Introduction

The theme of National Chemistry Week (NCW) for the year 2000 was "Kitchen Chemistry," and one of our contributions to this American Chemical Society annual event popularizing and emphasizing the applications of chemistry to everyday life was our article on gazpacho [1]. We now wish to consider the chemistry of another tasty and nourishing dish. The production of a ripened or cured cheese such as Swiss cheese as a lecture demonstration or laboratory experiment would be too complicated and time-consuming; however, in the hands of a creative and imaginative chemical educator the preparation of Swiss cheese fondue from commercial cheese can add a stimulating and motivating dimension to the lecture hall or laboratory. It illustrates in a novel, simple, and rapid manner several fundamental principles of colloid and acid–base chemistry. And, unlike the products of most chemical syntheses, the results can be sampled and eaten.

Biotechnology

Because biotechnology is one of the "hottest" areas of research, industrial growth, and investment today, many persons may consider it a modern development; however, cooking, baking, brewing, cheese making, and other basic biotechnical reactions were well known to the ancient artisans who were the ancestors of modern chemists.

Our favorite recipes, handed down through time or gleaned from the latest cookbook, may be the oldest and most practical applications of chemical research. Every cook is a practicing chemist who applies fundamental chemical principles whether or not he or she is aware of this. At every opportunity we need to impress this fact upon our students and the public, who regard chemistry as an esoteric science unrelated to everyday life.

Dairy Products

Cheese is made from milk, which, as mammals (from the Latin *mamma*, breast) we have imbibed from our mother's breast as our first food from the inception of our species at least a million years ago. Humans, however, probably began to drink the milk of other mammals regularly only after the domestication of animals (sheep, goats, and cattle, 11,000, 9,500, and 8,500 years ago, respectively) that were first used for meat and skins. Dairying was known by 4,000 BC, and the remains of cheese have been discovered in Egyptian tombs dating from 2,300 BC [2, 3]. Dairy products, along with such fermentation products as bread, beer, and wine, constitute some of the earliest applications of chemistry and microbiology to everyday life—the beginnings of biotechnology.

Cheese is perhaps the oldest processed food known to humankind and one of the most ubiquitous and popular foodstuffs in the world [4]. The National Cheese Institute reported that Americans consumed 8.5 billion pounds of cheese in 1992 [3], while, according to the U.S. Chamber of Commerce, per capita consumption of cheese in the United States increased almost 60% between 1980 and 1997 with a sharp upturn in 1999 (possibly due to the "Behold the Power of Cheese" advertising campaign) that has continued into 2001 [5].

Cheese may have originated from milk stored in pouches of animals' stomachs, that coagulated into curds [2, 6]. The Greek historian Xenophon (431 BC–ca. 350 BC) reported that a goat cheese had been known for centuries in the Greek peninsula of Peloponnesus [6]. In his *De rei rusticae* (*On Rustic Matters*, ca. AD 65) Roman soldier and farmer Lucius Junius Moderatus Columella's description of crude cheese making does not differ very much from current practice:

> [Milk] should be curdled with rennet [*coagulum*] obtained from a lamb or kid, though it can also be done with the flower of the wild thistle [genus *Cirsium*] or the seeds of the safflower [*Carthamus tinctorius*], and equally well with the liquid which flows from a fig-tree [genus *Ficus*] if you make an incision in the bark while it is still green [7].

By the time that the Hebrew Bible began to be written (about three millennia ago), dairy products were familiar enough to be used as metaphors. Canaan is described as a land "flowing with milk and honey" [8], and in Job's expostulations with God, he asks, "Hast thou not poured me out like milk, and curdled me like cheese?" [9]. The phenomenon of curdling intrigued those who pondered the transition from chaos to order. For example, in *On the Generation of Animals* (περι ζϖϖν γενεσεϖs), Aristotle (384 BC–322 BC) wrote,

> The male provides the "form" and the "principle of the movement," the female provides the body, in other words the material. Compare the coagulation of milk. Here, milk is the body, and the fig-juice or rennet contains the principle which causes it to set [10].

A number of chemical words are derived from the Greek and Latin words for milk ($\gamma\alpha\lambda\alpha$ and *lac*, respectively) [2], for example, the monosaccharide (+)-galactose, $HOCH_2(CHOH)_4CHO$, formed (along with (+)-glucose) by the hydrolysis of the disaccharide lactose, 4-*O*-(β-D-galactopyranosyl)-D-glucopyranose, $C_{12}H_{22}O_{11}.H_2O$ (milk sugar), which consists of one galactose and one glucose unit joined together [3].

Although dairy products were important foods all over early Europe, preferences varied with the climate [2]. Neither perishable fresh milk nor butter, which would sour, was popular in the warmer climes of Greece or Rome, while the more stable cheese was a staple. In northern Europe and Asia the reverse was true. Milking, churning, and cheese making were all difficult work, done by hand and mostly by women (Our word "dairy" is derived from "dey" meaning female servant in Middle English and kneader or bread maker in Old English) [2]. The production of cheese, yogurt, and other fermented dairy products was largely uncontrolled, and the microbes, whether desirable or not, came from the air or the previous batch of milk. By the turn of the 20th century, purified bacterial cultures resulted in much better quality control [2]. In February 2001 at the annual meeting of the American Association for the Advancement of Science, a symposium was held on the chemistry and technology of wine and cheese—both ancient foods that originated as ways to preserve perishables [11].

Cheese Making

Milk is a complex material consisting of milk fat, complexes of protein and salts, and sugar, vitamins, and other salts and proteins dissolved in the water that makes up the bulk of the fluid. The milk fat exists as globules, about 1–5 microns (0.0001 inch) in diameter, of a triglyceride wrapped in a phospholipid-protein (phosphate-fatty acid complexes) membrane. The membrane stabilizes the globules by preventing them from clumping together into a large mass of fat [2, 3].

The major milk protein, casein (from the Latin *caseus*, cheese), is a mixture of molecules with molecular weights ranging from 75,000 to 375,000 Daltons and comprising about 82% by weight of the proteins of cow's milk, the other 18% being whey [3, 4]. It consists of several different components, bundled together, along with calcium and phosphate ions, into colloidal aggregates (micelles) about 0.1 micron in diameter, which, along with the larger fat globules, deflect light rays to give the fluid its milky, opalescent appearance. A major casein component contains a subunit that stabilizes that component and keeps it dispersed in separate micelles. If this shielding subunit is removed, for example, by the enzyme rennin, the micelles react with calcium ions, which act as bridges between them, causing them to clot together and form the curd that is used to make cheese [2].

Coagulation can also be induced by other methods, such as adding acid or salts [12, 13]. Proteins have a specific pH range within which they will aggregate, whereas outside this range they possess an electric charge that makes them mutually repellent. If the pH of milk is reduced to 5.3 to 5.5, the casein micelles lose their negative charges and clump together into a curd. Similarly, adding salt (cations and anions) changes the electrical environment and produces the same effect, but the amount of salt needed is too much for the palate [2].

Cheeses differ from other cultured milk products such as yogurt, buttermilk, or sour cream in the further extent to which curdling and fermentation are permitted to proceed [2]. In cheese making, a starting culture of bacteria (lactic *Streptococci* or *Lactobacilli* normally found in raw milk) is added to warm milk to convert some of the lactose to lactic acid ($CH_3CHOHCOOH$) [14]. This lowers the pH of the slightly acidic milk from its usual 6.5–6.7 to about 5.3–5.5. The milk is now acidic enough for the enzyme rennin, also called rennet or chymosin (originally obtained by soaking the fourth or true stomach of a milk-fed calf in brine, but now also derived from molds), which is next added, to hydrolyze proteins and cause the casein to precipitate into a soft solid or curd (calcium caseinate and milkfat), while the whey remains suspended in the liquid [2–4].

The more acidic whey (pH 4.6–4.7), containing soluble proteins and lactose, is removed, and the curd is stirred and heated, salt or brine is added, and the cheese is pressed into molds. For ripened cheeses the curd is treated further with bacteria, mold, or yeast that produce enzymes to hydrolyze fats (lipases), proteins (proteases), and lactose (lactases) and yield smaller, volatile molecules that produce the distinctive flavor, smell, and texture of the cheese as it ages. Sometimes gases such as ammonia (NH_3) and carbon dioxide (CO_2) are formed; when these gases cannot escape, holes ("eyes") are formed as in Swiss cheese [3, 15]. Ripening may last from one month to three years depending upon the type of cheese; the longer the ripening period, the sharper the cheese [14]. Almost all the water and sugar of the milk are removed in cheese making; 100 lb of milk is required to make 9.5 lb of cheese [3]. Because cheese, yogurt, and other cultured dairy foods are almost free of lactose, they may cause less digestive distress to lactose-intolerant persons than do milk and other milk products [2].

Fondue

Fondue (from the French for "melted") is the national dish of the world's oldest surviving democracy (Swiss Independence Day is August 1, 1291). Although popular in its homeland since time immemorial, it achieved international recognition only in the 1800s when it was rediscovered and publicized by famed French gastronome Jean-Anthelme Brillat-Savarin (1755–1826) [16]. Possibly because of its high fat and cholesterol content, it seems to have fallen into disfavor by a health-conscious public, but recent numerous advertisements for fondue sets in newspapers around the country seem to herald its renaissance.

Fondue originated in practical necessity rather than *haute cuisine*. In prehistoric Swiss households, cheese and bread—then the staples of their diet—were made in summer and fall to last all through the long winter. Both became too hard to eat, so some nameless but ingenious Neolithic gourmet, with an uncanny knowledge of what would later come to be known as colloid chemistry, discovered that melting cheese in wine resulted in a delicious mixture in which the hard bread could be dunked, and—Voilà, fondue was invented! [16].

Stirring cheese into hot liquids can be tricky, for if overheated the casein can separate into stringy masses. Cornstarch is added to prevent this [5]. Furthermore, the dry

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white wine used in preparing fondue is usually acidic enough to prevent stringiness and lowers the boiling point so that the protein does not curdle [2]. Also, the citric acid in the lemon juice that is added combines with the calcium ion in the cheese to prevent stringiness [17]. High-fat cheeses melt better than low-fat cheeses.

To guarantee the genuine Swiss taste, natural cheeses not pasteurized types should be used. We recommend imported gruyère (sharper) or a mixture of gruyère and emmentaler (milder) cheese. These are hard cheeses (30–40% water, 30% fat, and 25% protein) that are aged for three to ten months. If desired, crab or lobster meat, mushrooms or morels, and herbs such as parsley, dill, chervil, and tarragon may be added [18].

Although not as ritualized as the Japanese tea ceremony, the serving of fondue and its concomitant communal spearing and dunking is a social ceremony with its own set of customs. If a woman loses her bread-cube in the fondue, she kisses the nearest man. If a man loses his bread, he provides the next round of drinks (It's not good form to get caught making anyone else "lose" his or her bread) [16]. Midway through the meal the more adventurous diners may chug-a-lug a jigger of *Kirschwasser* (cherry brandy), which connoisseurs call *le coup de milieu* (*Caveat:* It's 90 proof—45% alcohol) [18].

Fondue makes a simple but festive cold-weather meal. Numerous recipes appear in various cookbooks [19, 20], but we prefer to follow the directions below, which we translated from a Swiss German recipe [18] and adapted for American (nonmetric) kitchens.

Swiss Cheese Fondue

Makes six servings

1 pound (454 g) gruyère cheese
1 pound (454 g) emmentaler cheese
1 loaf French bread
1 garlic clove
20 fluid ounces (591 ml) white wine
1-1/2 teaspoons (8.25 ml) cornstarch
2 fluid ounces (59 ml) *Kirschwasser*
1 tablespoon (16.5 ml) fresh lemon juice
pepper and nutmeg (freshly ground, if possible)
1 pinch baking soda (sodium bicarbonate)

• Cut bread into 1-inch cubes with plenty of crust on each piece.
• Grate and mix the two cheeses.
• Rub bottom and sides of a 2-quart casserole with garlic and drop in crushed clove.
• Add wine to casserole and heat moderately (don't boil).
• Have all the ingredients ready to add with one hand because the other hand will be busy stirring the mixture with a wooden spoon from the time that the wine is hot enough for the cheese to be added until the fondue is ready to be eaten (about 10 minutes).
• Add cheese mixture gradually and stir in a figure eight (Don't worry if two phases form at this point). Add a handful at a time, stirring until the cheese is melted before adding more.
• As soon as the mixture begins to boil add cornstarch, which has been stirred into *Kirschwasser*.
• Gradually stir in the lemon juice.
• Keep stirring.
• Season with pepper and nutmeg to taste.
• Add baking soda to "lighten" (causes effervescence: $NaHCO_3$ + $HOOCCH_2C(OH)(COOH)CH_2COOH \rightarrow Na^+$ + $HOOCCH_2C(OH)(COOH)CH_2COO^-$ + CO_2 + H_2O).
• Bring casserole to serving table over heating unit to keep mixture bubbling lightly. Swirl to keep the fondue in motion.
• Guests spear bread cubes from the hard side on fondue forks, dunk into fondue with stirring motion, and… Bon appétit!
• At first the fondue will be on the thin side but will thicken as the process progresses.
• If two phases form during the meal, heat further, stir vigorously, and add another 1/2 teaspoon cornstarch stirred in wine.

Further Activities

For recipes and explanations of the chemistry involved in food preparation, you may wish to consult the useful and interesting books by Atlanta cooking teacher and food consultant Shirley O. Corriher [17] and McGill University chemist Arthur E. Grosser [21, 22].

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