# CHAPTER 18. CONSUMER CHOICES: FOOD AND FOOD ADDITIVES

The Professor to his cook: You are a little opinionated, and I have had some trouble in making you understand that the phenomena which take place in your laboratory are nothing other than the execution of the eternal laws of nature, and that certain things which you do without thinking, and only because you have seen others do them, derive nonetheless from the highest scientific principles.
Brillat-Savarin, "The Physiology of Taste" (1825), as quoted by Harold McGee
    in "On Food and Cooking."

Why Eat?

Before examining consumer issues related to food, we will start with first principles: what is "food," and why do we need to eat it? The simple answer to these questions is that foods are those substances we need for energy to operate our bodies, and as building material for making our bodies. We already have considerable understanding of what happens in these processes based on chemical principles from earlier chapters.

In Chapter 14, "A Chemist's Perspective on Ecology: the Interlocking Chemistry of Plant and Animal Life," we learned that animals derive energy from a series of biochemical oxidation-reduction reactions, and that the overall, or net chemical reaction expressing this process, called cell respiration, is as follows:

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + energy \qquad (14\text{-}2)$$
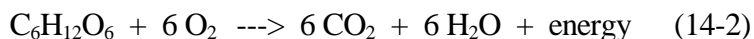
The energy-releasing reaction used by the body described by this net chemical equation requires one glucose molecule and six oxygen molecules, and results in six carbon dioxide molecules and six water molecules as products. To keep this reaction going, the body always carries in the blood a certain level of glucose, or "blood sugar". But we don't have to keep eating the simple sugar glucose in order maintain this necessary glucose level in the blood; as a matter of fact, there is evidence that eating too much sugar can strain the body's biochemical mechanisms for maintaining a constant level. As we learned in Chapter 15, "Biochemistry: the Chemicals of Our Bodies," starches are long-chain molecules made up of glucose units strung together. When we eat starch, from wheat, rice, potatoes, or other plant sources, the body breaks apart the bonds between the glucose units, slowly releasing glucose into the bloodstream. Thus, plant starches are a particularly good source of animal energy. But the body's biochemistry is versatile, and if necessary, fats, proteins, or even alcohol can be used in biochemical reactions to produce a source of energy if necessary. Thus, any of the major components of the diet can be used for energy.

Besides meeting the need for fuel for the body, food must also provide the essential building materials for the body itself; among the necessary components are certain amino acids, fats, minerals, and vitamins. Proteins, needed for muscle and other body components, are chains of amino acids. Of the twenty amino acid components needed to make proteins, eight cannot be synthesized by the body and must be taken in as food. These "essential amino acids" are listed in Chapter 15. Small quantities of certain fats are needed as well, to make certain components of body cells and as starting material for essential biomolecules. For example, in Chapter 15 we saw how linoleic acid, one of the fatty acids essential to the diet, is used in the body as a starting material for making prostaglandins, which have an important role in regulating body functions. Minerals are inorganic, or non-carbon, compounds, like calcium and iron. Of course, when we say "we need calcium and iron in the diet," we are not referring to bits of the highly reactive metallic element calcium or the metallic element iron, but to compounds of these elements. Chief minerals required by the body are calcium and phoshorous, for making bones and teeth. Traces of other minerals like iron, zinc, iodine, magnesium, and copper are needed as well for making essential body molecules. For example, the structure of the hemoglobin molecule shown in Chapter 16 requires iron as an essential part of this molecule that carries oxygen through the body. Vitamins are molecules we need for important reactions within the body, and which the body cannot synthesize for itself. Often vitamins serve as catalysts or "cofactors" for biochemical reactions.

Today our eating habits sometimes seem to have little relationship to basic body needs. Convenience, attractiveness, flavor, and cultural acceptance can be at least as important as nutrition in determining consumer food choices. In recent years, as research data has been building about the importance of diet in maintaining health, consumers have been showing more interest in the nutritional value of foods. With growing public concerns about nutrition and food safety, food advertising has become inceasingly replete with nutritional information, and sometimes misinformation. In the complex situation presented by the supermarket of today, our knowledge of basic chemical concepts can be very useful as a basis for consumer choices about foods.

Preserving Food: the Alternative to Spoiling Food

In general, the freshest food is the most desirable food. The vine-ripe tomato picked fresh from the field has an unbeatably delectable flavor and aroma, and a high nutrient content as well. The level of some vitamins like vitamin C tends to diminish in foods with time. Moreover, very quickly, microorganisms go to work in fruits and vegetables, producing spoilage. Meat, milk, and bread, likewise, are fertile fields for the growth of microorganisms. Yet most people nowadays live far from the sources of the fruits and vegetables, meat and milk they consume, and our "daily bread" no longer is the product in most homes of daily baking or a trip to the bakery. Most people, then, eat some foods that are preserved in some way. Should we be concerned about preservatives and "chemicals" in our food? What are the issues we should understand in order to be sure of eating safe and wholesome foods?

Freezing and Dehydration; Why Do They Work?

Spoilage, whether of fruits and vegetables or of meats, has two primary causes: microbial action (bacteria or molds) and the action of enzymes which are normal components of the produce or meat itself. Both these types of processes, like most chemical reactions, are slowed by lowered temperature, and hence refrigeration slows down spoilage. Refrigeration is much less effective with fish than with meat, however; since fish are cold-blooded and most live in cold water, their enzymes are designed to work at low temperatures. As a result, fish spoils quickly, even when refrigerated. At best, biochemical processes are not stopped by refrigeration, but only slowed down. Deterioration by microbes continues in both meat and produce. Plant tissues in harvested fruits and vegetables are still alive and respiring, and need air for this continuing biochemical process. Deprived of air in closed plastic bags, fruits and vegetables simply switch from aerobic respiration to anaerobic respiration, a process which forms alcohol in plant tissues, causing brown spots.

The control of food-borne micro-organisms is important, not just in maintaining quality of food, but also its safety. Pathogenic bacteria like Salmonella can be a serious threat to public health, and some micro-organisms like Clostridium botulinum and Staphlococcus aureus produce toxic substances which will remain in the food even if the bacteria are killed.

Freezing does more than simply to lower the temperature further than refrigeration. Below 0° C, the water molecules undergo a phase change from the liquid phase to the solid phase; in the solid crystal lattice the water molecules are much less available to participate in chemical reactions, and hence the biochemical reactions of spoilage which take place in aqueous solution are slowed drastically. Dissolved salts lower the freezing temperature of water, and as early as the 16th century, this principle was used to produce "super-cold" ice for freezing foods. About 1880 freezing began to be widespread in the meat-packing industry, and in 1923 Clarence Birdseye founded a company based on the process of quick-freezing, which minimizes loss of food quality. As meat or produce freezes, ice crystals form in the intracellular spaces; cell walls rupture, affecting the texture and quality of the product. Quick-freezing results in smaller water crystals, and hence higher food quality. Sometimes vegetables are blanched, or immersed in boiling water briefy before freezing. The high temperatures change the chemical structures of the natural enzymes, rendering them inactive, and extending the storage life of the frozen vegetable even further.

Dehydration, or drying of food, removes water and hence greatly decreases the rate of most spoilage reactions, which take place in aqueous solution. Thus, the chemical basis of dehydration is similar in some ways to that of freezing. Dehydration is a very old method of meat preservation, in use at least as early as ancient Egypt. Native Americans made pemmican, a highly nutritious and food, from dried meat, fat, and berries. This long-lasting and portable food product was the precursor of the freeze-dried foods of today used by campers and the military. In freeze-drying, the food is first quick-frozen, then dehydrated under low pressure.

Ancient Additives: Salt and Sugar

Adding lots of salt or sugar to a food kills bacteria and molds or slows down their growth drastically by drying up their cells. The principle by which this works is called osmosis. When the concentration of dissolved material on one side of a membrane is greater than on the other side, water will tend to migrate through the membrane from the side with lower concentration to the side with

higher concentration until the concentrations on each side of the membrane are equal. For example, when bacteria find themselves in a highly concentrated solution of salt or sugar, water migrates out through the membranes of their cell walls to make the surrounding solution more dilute and the concentration of dissolved substances inside the cells more concentrated in a kind of "balancing act." If the surrounding solution contains high enough concentrations of dissolved material, the bacterial cells become too dried out from this process to be able to function, and the bacteria may die.

Through osmosis, bacterial cells which are immersed in concentrated solutions become dehydrated.
http://www.tvdsb.on.ca/westmin/science/sbi3a1/Cells/Osmosis.htm

Jellies and jams are preserved using this principle of using osmosis to dehydrate microbe cells, with sugar as the dissolved material. If water condenses on the surface of the jam or jelly, mold may start to form there; that is why a paraffin wax seal is often used.

Food preservation recipes using salting techniques have been known for centuries, as in the following recipes quoted in Harold McGee's "On Food and Cooking":

Bacon, to dry: Cut the Leg with a piece of the Loin (of a young Hog), then with Salt peter, in fine Powder and Brown Sugar mix'd together, rub it well daily for 2 or 3 days, after which salt it well, so it will look red: let it lye for 6 or 8 Weeks, then hang it up (in a drying-place) to dry.
William Salmon, "The Family Dictionary: Or, Household Companion," London, 1710 (4th edition)

To Pickle Pork: Put a Pound of Salt-petre; and two Pounds of Bay-salt to a Hog.
Hannah Glasse, "The Art of Cookery," London, 1748.

Salted meats like these and salted fish, like salt cod from Newfoundland, were the primary source of meat in the diet for all but the wealthiest Europeans in the 17th and 18th centuries. In America game was plentiful, and fresh meat commmon until the 19th century, when meats preserved by salting, especially salt pork, became a diet staple for an increasingly urbanized country. Per capita consumption of meat was very high, averaging 178 pounds annually in the decade between 1830 to 1840. The ubiquitous salt pork was stored in barrels, giving rise to the expression "pork barrel politics."

Nitrites: All Is Not Rosy with Cured Meats

The choice of which substance to use in "salting" meat has an interesting history. As we learned in Chapter 5, a "salt" is an ionic compound. The salts used in preserving meat are all ionic compounds with sodium or potassium as the cation, or positively charged ion, and chloride, nitrate, or nitrite as the

anion, or negatively charged ion. Originally brine (stong salt water) was used, or large grains of salt (called "corns," as in "corned beef"). The salt not only preserved and flavored the meat, but gave it an attractive bright pink color, rather than the normally grayish color of old meat. This color was caused not by the sodium chloride which was the main chemical compound in the salt, but by an impurity, sodium nitrate. The nitrate ion is changed to nitrite ion by the action of bacteria in the meat, and the nitrite reacts with the muscle pigment myoglobin in a series of reactions to produce nitrosomyoglobin, a pink-colored compound. Saltpeter, or potassium nitrate, was discovered in the Middle Ages as a crystalline outgrowth on rocks, and gained use both as a fertilizer, and, even more important historically, in making a new product, gunpowder. By the 16th or 17th centuries, as we see from the recipes of William Salmon and Hannah Glasse, the action of nitrate in curing meat became known, and saltpeter became popular in recipes for salted meat.

It is now recognized that, since nitrite and not nitrate is actually the anion that produces the pink color, nitrite can be added in small quantities rather than using larger quantities of nitrate. Even in small amounts nitrite gives the characteristic pink color and "cured" flavor to meats. Moreover, nitrite appears to be especially effective in inhibiting the growth of bacteria. Since 1923 a curing method using nitrite and a reduced overall salt content has been in use for many meat products. Ham made by this process, unlike that made using earlier methods, do not contain such a high salt content that they need to be soaked in water overnight, then boiled before use. Unlike the more heavily salted meats, these products require refrigeration to further retard bacterial growth.

Though, as we have seen, nitrites have been present in salted meats for centuries, their safety has been the subject of some controversy in recent years. In 1956 it was shown that nitrite ion can combine with the amine functional group on amino acids or other organic compounds found in the body to form compounds called nitrosamines, which are known to cause cancer in animals.
The concern about nitrite in the diet increased in 1978, when one experimental study seemed to show that nitrite itself was a carcinogen in rats. Though this result was later found to be erroneous, the concern remained that cancer-causing nitrosamines can be formed by the reaction between nitrite and amines in acid conditions like those of the human stomach. Nitrites in food, however, are not the only source of nitrites in the body; bacteria present in saliva, for example, can change nitrates, commonly found in many foods including fresh vegetables, to nitrites. It has been estimated that the average American's intake of nitrite from food is 2.6 mg each day, while that produced from nitrate by saliva is about 8.6 mg. In 1980 the Food and Drug Administration and U.S. Department of Agriculture decided not to ban nitrites from food. Some health experts recommend that the safest policy is for individuals to eliminate or limit salted meats like ham, bacon, and hot dogs as a dietary source of nitrite.

Organic Acids as Preservatives

Today's food market carries a much greater variety of preserved foods than the dried or heavily salted and sugared products of earlier times, largely because of the availability of preservative chemicals. One of the most common of these is benzoic acid (which inhibits the growth of bacteria in

food. Many berries naturally contain appreciable amounts of benzoic acid, on the order of 0.05%, but most benzoic acid in foods has been added as a preservative. Often it is added in the form of sodium benzoate or potassium benzoate, salts of the acid, which in acid solutions with pH less than 4.5 form benzoic acid by reacting with H^+. Among foods which often contain benzoic acid or sodium benzoate are soft drinks and fruit juices. Other organic acids used in foods are propionic acid and its salts sodium propionate and calcium propionate, used to prevent mold in bread, and sorbic acid and its salt potassium sorbate, used in cheese, wine, chocolate syrups, margarine, and fruit-juice drinks.

Antioxidants as Preservatives

The most important class of food additives are the antioxidants, used to prevent the oxidation reactions which cause fats to become rancid. These reactions take place most readily in unsaturated fats, because the carbon atoms next to carbon-caron double bonds react with oxygen, making organic compounds called hydroperoxides. Hydroperoxides react further, breaking apart to form aldehydes, ketones, and lower-molecular-weight acids, typically odorous compounds that produce the smells of rancid fat. Polyunsaturated fats, those with more than one double bond, are especially prone to this type of oxidation, because they can have a carbon atom located between two double bonds, with both double bonds acting to enhance the formation of hydroperoxides at that site.

It is unfortunate that the unsaturated fats, those thought to be most healthful for the coronary arteries, are those most likely to go rancid. What can the consumer do to ensure fresh-tasting and healthful products? Storage in the refrigerator will help, as lowered temperature slows reaction rates. Some products come in brown bottles or cans, because light activates the process. Cooking oils should not be repeatedly re-used, because of the chemical by-products they contain. And, finally, antioxidant chemicals added to foods containing fat can help to block the chemical reactions that cause the oxidation of fats.

Chemicals added to fats to prevent oxidation are of two basic types: antioxidants, which react with oxygen molecules that would otherwise react with fats and cause rancidity; and sequestrants, which tie up metal ions that catalyze the process. Common antioxidants are BHA (butylated hydroxyanisole), BHT (butylated hydroxytoluene, and tocopherol (vitamin E). Of these, vitamin E occurs as a natural antioxidant in grains and vegetable oils, and BHA and BHT are chemically synthesized. Ascorbic acid (vitamin C), another natural antioxidant, is also used as a food additive, but, because it is water-soluble instead of oil-soluble, it is not useful for preventing the oxidation of fats, though it is used in fruit prodcuts. Another water-soluble antioxidant closely related to ascorbic acid is erythorbic acid; its salt, sodium erythorbate, is used in meat products.

A commonly used sequestrant is ethylenediaminetetraacetic acid, or EDTA.
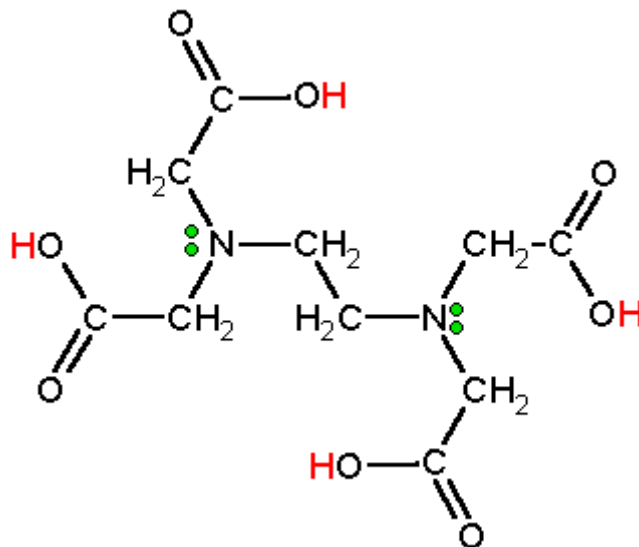
DECODING CHEMISTRY: ethylenediaminetetraacetic acid

Here is a sterling example of a chemical name with an intimidating appearance; no wonder it is usually referred to as EDTA! However, even with limited experience in decoding chemical names it is easy to pick apart the name of this common food additive into meaningful parts:

ethylene	The compound has a 2-carbon "backbone."
diamine	The compound has two amine groups.
tetraacetic acid	The compound has four acetic acid groups

EDTA is a chelating agent, a name that refers to the resemblance of the compound to a crab with claws that grab on to a metal ion from different directions- in this case the claws are the carboxylic acid groups, in which the H can be replaced by the metal; the resulting compound of an EDTA wrapped around a metal ion is called a complex ion. Metal ions like copper or iron that could catalyze oxidation are "tied up" in the complex ion form by this chelating agent, and thus oxidation is prevented. Sequestrants are used for many commercial purposes besides inhibiting rancidification of fats. In soft drinks, for example, they tie up metal ions that might otherwise form precipitates and cause cloudiness. EDTA has even found a medical use in cases of lead poisoning. The EDTA reacts with the lead ion, forming a complex ion that can be excreted in the urine. A very familiar use of EDTA is in mayonnaise; especially near the metal cap, metal ions may catalyze oxidation of the fat in the mayo and cause rancidity. EDTA ties up the metal ions to prevent this. It's even an ingredient in the Big Mac special sauce!

Other commonly used sequestrants in addition to EDTA are citric acid and its salts, and phosphate compounds.

Flavor agents

Preserved food usually loses some of its appeal in color, flavor and texture, both from deterioration which is only slowed, but not totally halted, by preservation, and also from the preserving process itself. Frozen foods, as we have seen, suffer in texture as cell walls are ruptured, and in flavor as liquids flow out of the cells to be lost as "drip." Canned foods have usually undergone heating to kill microorganisms before being sealed, and have may thus suffered from the chemical decomposition of naturally-occurring substances which give flavor. Flavoring, coloring, and texturizing agents can be added to enhance the appeal of such preserved products to the consumer. An even greater market for these chemical agents is created by the increasing number of "food products" like soft drinks that are mainly or wholly composed of synthetic chemicals. Salt and sweeteners, of course, enhance the taste of foods and are often used in heavy quantities in highly processed foodstuffs; in addition to these. a very large number of organic compounds are included in the category of food additives known as flavors. Some chemical compounds used as flavors are benzaldehye (maraschino cherries), cinnamaldehye(cinnamon), 1-malic acid(apple) , ethyl butyrate (pineapple).

Over 1400 chemical compounds are used for flavoring; most of these occur naturally in foods or in plant products like vanillin that have been used for centuries to add flavor to foods. There is a heavy demand for chemical products that will lend a naturally appealing flavor to foods, but the obstacles to the chemist in producing artificial flavors are great. First, the chemical components that are responsible for natural flavors must be isolated and identified, a process made more difficult by the sheer number of these compounds. For example, a study of the volatile compounds in Scotch whiskey yielded 313 different compounds, including 32 alcohols and 22 esters. Even if all the volatile components of a food are identified, there is no chemical way of determining which of these contributes to the flavor or aroma of a food. Each component must be isolated or synthesized in the laboratory in sufficient quantities to be tested for a human response to its odor and flavor, if any. The work of the flavor chemist is very much in demand, for a recipe that duplicates an appealing natural flavor can have great commercial value. One example of a relatively complex flavor recipe is that of strawberry, shown below.

Components of synthetic strawberry flavoring (from U.S. Patent No. 3686004, as quoted in Coultate, "Food: The Chemistry of Its Components"

Chemical compound	Relative quantity
Geraniol	1
Ethyl methyl phenyl glycidate	3
2-Methyl-2-pentenoic acid	5
Vanillin	6
Ethyl pelargonate	13
Isoamyl acetate	14
Ethyl butyrate	52
1-(Prop-1-enyl)-3,4,5-trimethoxybenzene	11

Some flavors are more easily replicated than others; the number of flavor chemicals present in apple juice is relatively few. For that reason, adulterated apple juice, a product in which the natural fruit flavors are partially or even totally replaced by synthetic chemicals, has caused regulatory problems. The presence of synthetic products, those made in the laboratory, is not in itself unlawful. For example, as we have seen, many soft drinks are wholly artificial products. Falsely labelling a product, however, is illegal, as in the case of a mixture of chemicals similar to apple juice being sold as a fruit product when it is actually a synthetic one.

Fruit flavors are not the only flavor chemicals that have been identified. Bitterness (as in some beers), astringency (as in wine and tea), and even meatiness, like all flavors, are caused by the presence of certain characteristic chemicals. Four aldehydes together give the aroma of cooked chicken.

These four aldehydes combine to produce the odor of cooked chicken.
(from Coultate, p. 179;

$CH_3CH_2CH_2CH_2CH_2CH=CHCH_2CHO$ 3-cis-nonenal

$CH_3CH_2CH_2CH_2CH_2CH=CHCH_2CH_2CHO$ 4-cis-decenal

$CH_3CH_2CH_2CH_2CH_2CH=CHCH_2CH=CHCHO$ 2-trans,5-cis-undecadienal

$CH_3CH_2CH_2CH_2CH_2CH=CHCH_2CH=CHCH=CHCHO$ 2-trans-4-cis,7-cis-tridecatrienal

DECODING CHEMISTRY   NEW TERMS: CIS AND TRANS

In the figure above the names of the four compounds that produce the smell of cooked chicken are relatively easy to decode. Let's look at cis- nonenal, the structure of which is given below:
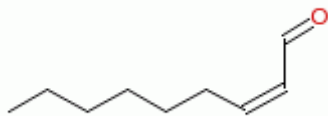
The lines are understood to connecting invisible carbons, so there are nine carbons, hence "non"- can you "see" them? At the end is a carbon double-bonded to an oxygen, so this is an aldehyde (hence "al") . The "en" means there is a double bond, which we see in the chain. But what about the "cis"? That means that the carbon chains are on the same side of the double bond (here shown as the top), and the invisible hydrogens that make up the fourth bonds on the double-bonded carbons are also on the same side. If they were diagonally opposite from each other, the name would be "trans" instead of "cis". This may seem to be a small difference, but it seems to make a big difference when substances interact with the body's chemicals. The solid fat that is formed from the hydrogenation of liquid fat has the trans configuration in its remaining double bond, and has recently been shown to be a big contributor to heart disease, so much so that cities are now banning its use.

Like most other natural flavors, the flavor of meat is caused by a mixture of chemical substances. Two substances in particular are associated with meat flavor: inosine monophosphate (IMP), isolated from dried fish; and monosodium glutamate (MSG), found in seaweed. Monosodium glutamate is the sodium salt of the amino acid glutamic acid, and IMP is a nucleic acid with the characteristic nucleic acid components of a phosphoric acid unit, a sugar unit, and an organic base unit.
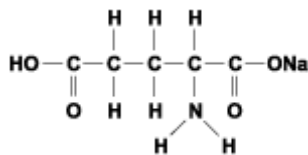
Monosodium glutamate is the sodium salt of the amino acid glutamic acid

IMP is a nucleic acid with the characteristic nucleic acid components of a phosphoric acid unit, a sugar unit, and an organic base unit.

Both IMP and MSG can now be made through biotechnology (by enzymatic hydrolysis of yeast RNA for IMP, and by bacterial fermentation for MSG). These substances are unusual in that neither has a strong flavor by itself, but when they are mixed together in equal proportions, the flavor becomes 20 times stronger. The mechanism by which this happens is not well understood, but the phenomenon has

been long been used in Asian cooking by adding MSG to enhance food flavors. Many processed foods, including soups, meats, and salad dressings, contain added MSG to boost their flavor; IMP is used also as a food flavor enhancer, though not as widely as MSG.

Found naturally in meat muscle, both MSG and IMP were assumed to present no hazard as additives until 1968, when it was shown that in some people MSG causes headache, tingling of the arms and neck, shortness of breath, and chest pain. First described by Dr. Robert Ho Man Kwok after dining experiences in Chinese restaurants, this effect became known as Chinese restaurant syndrome. The magnitude of the physiological reaction to MSG seems to vary from one person to another, those with asthma or allergic senstivites being particularly vulnerable. In 1969 neurophysiologist John Olney found that oral doses of MSG raise blood glutamate levels and causes damage to the hypothalamus region of the brain, especially in infant animals. He concluded that humans might be at risk for brain damage from MSG, with children and infants most vulnerable. MSG was voluntarily withdrawn from baby foods because of these concerns. However, research results on MSG were reviewed by a committee of the National Academy of Sciences in 1970, and by the Federation of American Societies for Experimental Biology in 1978 and again in 1980, with the conclusion that MSG was safe as a food additive, and its FDA approval remained unchanged. Neuroscientists remain interested in the effects of glutamate on the brain. The amino acid is known to function in the body under normal conditions as an excitatory neurotransmitter, which is released by neurons and then stimulates other neurons to higher levels of activity. Olney found that, when present in excess, glutamate can act as an excitotoxin, stimulating nerve cells until they die. Other excitotoxin compounds in the diet have been linked to neurodegenerative conditions in parts of Africa, and Guam; the relationship between excitotoxins and neurological disease is still under study.

Coloring Agents

Color plays an important role in our enjoyment of food. The deep red of ripe cherries and apples, the yellow of bananas, the golden brown crust of bread all lend to their appeal. Or to look at it another way, if cherry pie, bananas, and bread could somehow be colored gray, we'd be unlikely to enjoy them fully even if they tasted the same as the naturally colored foods. Even when the coloring is artificial, it can be necessary for consumer acceptability, as, for example, the pink color given to ham and other cured meats by nitrites.

Molecules of colored compounds absorb light in the visible part of the electromagnetic spectrum (discussed in Chapter 2). Since the colorless light shining on the molecule is actually made up of all colors of the rainbow, the light reflected back to the viewer will consist of the light that was shining on the sample minus the part that was absorbed by the sample. For example, if blue light is absorbed by a compound, we see yellow when we look at it. Table 18-X shows how absorption of a given wavelength of visible light can result in a colored appearance, which is actually the complementary color of the light being absorbed.

Colors Resulting from Absorption of Visible Light

Wavelength region absorbed (nm)	Color of light absorbed	Complementary color observed
400-435	Violet	Yellow-green
435-480	Blue	Yellow
480-500	Blue-green	Red
500-560	Green	Purple
560-580	Yellow-green	Violet
580-595	Yellow	Blue
595-650	Orange	Green-blue
650-750	Red	Blue-green

It is actually the electrons in the molecule which absorb the light energy, as they move to higher electronic energy levels within the molecule. Whether a molecule is colored, then, will, depend on the energy levels within the molecule, which in turn depend on the molecule's structure. A structure which features a number of double bonds alternating with single bonds meets that requirement, as in the natural yellow-orange colored compound carotene found in many fruits and vegetables (Fig. 18-X). Aromatic structures, those containing benzene rings or similar structures (Chapter 10), can also produce vivid colors. Aromatic dyes derived from coal tars are popular because of their bright colors, although these are often unnatural in their appearance as well as in their source.

The chemical structures and names of most food dyes are very complex, and typically they are known by the names by which they are identified under the Food, Drugs, and Cosmetics Act, like FD&C blue no. 1.

The Food and Drug Act of 1906 introduced the regulation of food dyes, as well as other food additives, in the United States, and listed those dyes that were in use at the time and believed to be safe. Several food dyes have been removed from the list since then. In 1950 a candy manufacturer used a high concentration of FD&C orange no. 1 in Halloween candy, causing severe gastrointestinal distress in a number of children, and that dye was then banned. An amendment to the Pure Food and Drug Act called the Delaney Amendment requires that any substance found to cause cancer in laboratory animals be banned as a food additive; FD&C red no. 2 and FD&C red. no.4 were removed from the approved list in 1976 because they were found to induce cancer in laboratory animals. Currently, only the following synthetic colors are allowed for use in coloring food, drugs, and cosmetics:

FD&C blue no. 1
FD&C blue no. 2
FD&C green no. 3
FD&C red no. 3
FD&C red no. 40
FD&C yellow no. 5

FD&C yellow No. 6
citrus red no. 2 (up to 2 ppm in oragne skins only)
orange B (up to 150 ppm in sausage casing only)

Sweeteners, Natural and Artificial

Sweetness is a universally appealing flavor. Even newborn babies have been shown to have a preference for sweetness. Sugars in foods are the prime source of sweet taste. In Chapter 15 we learned about the chemistry of sugars, including the important food sugars: the disaccharides sucrose and lactose, and the monosaccharides fructose, and glucose. Sucrose is found naturally in many plant materials, particularly fruits, and is produced commercially by extraction from sugar cane or sugar beet. Lactose, the sugar found in milk, is not well tolerated by individuals who lack the enzyme lactase (See chapter 15). The monosaccharides glucose and fructose occur abundantly in nature, with fructose found mainly in fruits and in honey. Fructose is much sweeter than sucrose; that is, it takes about 75% more sucrose to give the same sweet taste as fructose.

The commercial uses of these sugars are determined by their properties, and, of course, their prices. Because, unlike many sugars, sucrose crystallizes easily into solid form, it is used as table sugar and sold in grocery stores for use in home recipes. Glucose (often called dextrose in food labels) is less sweet than sugar, but is easily produced commercially by using molds to break down the starch polymer in corn into its glucose units to make glucose-rich corn syrup. Further treatment with bacteria, as described in Chapter 15, changes glucose to fructose and yields high-fructose corn syrup, sweeter to the taste because fructose is sweeter than glucose, and hence even cheaper to use commercially since less is needed to produce a desired level of sweetness. Another way of utilizing the high sweetening power of fructose is by breaking down the disaccharide sucrose into its component monosaccharides glucose and fructose, producing a product called "invert sugar." Honey contains glucose and fructose, produced by the splitting up of sucrose, and hence honey is sweeter than table sugar.

DECODING CHEMISTRY: It's easy to identify sugars: they always end in "ose"!

The development of artificial sweeteners is an interesting example of scientific discovery; however, the example should not be followed today, because artificial sweeteners were discovered by poor practices in the laboratory which resulted in tasting new chemical substances, a practice with potentially fatal consequences. Saccharin, the first artificial sweetener, was discovered in 1878 by Constantin Fahlberg, a German student working at Johns Hopkins University, when he noticed the piece of bread he was eating tasted very sweet. He soon realized that his hands had picked up a trace of a chemical compound from the laboratory, and that the chemical had been transferred to his food. After tests for toxicity in Europe, Fahlberg applied for a patent in 1894, and saccharin became widely adopted as a sweetener. Saccharin is 200 to 700 times as sweet as sugar, and has no caloric value, as it is excreted unchaned in the urine. Cyclamates, another type of artificial sweetener, were first noticed in 1937 at the University of Illinois, when chemist Michael Sveda found that a cigarette tasted sweet because it had absorbed a substance he was using in the laboratory. In the late 1960's laboratory studies of cyclamates showed an association with cancer in animals, and they were banned as sweeteners in the

United States.

Since saccharin is excreted from the body unchanged, it was assumed that no harmful interactions took place. In 1977, however, a laboratory study showed that saccharin increased the incidence of bladder cancer in rats. To this day the controversy remains as to whether saccharin represents a significant health hazard. Drawing comparisons from animal studies is always difficult; rats, for example, produce very concentrated urine in their bladders. On the other hand, it is always best to err on the side of safety when the health of millions is at stake. With substances that are shown to cause cancer in animals, however, the Delaney Amendment leaves no room for controversy; the substance must be banned. In the case of saccharin, the public outcry was tremendous. Cyclamates had already beeen banned in 1970, and, with the loss of saccharin, no
artificial sweetener would have been available for the production of diet sodas and other low-calorie products. By Congressional action, an eighteen-month moratorium on the banning of saccharin was imposed, which has since been renewed regularly, and saccharin is still in use in the U.S. as an artificial sweetener.

In 1965 in the laboratories of the drug company G. D. Searle, J. Schlatter, in yet another failure of laboratory hygiene, accidentally discovered on his fingers the sweet taste of a new compound he was working on as an anti-ulcer drug. In 1981 this new drug, aspartame, was approved for use as a sweetener in food, and in 1983 for use in carbonated beverages. The product is now marketed under the name Nutrasweet, and annual sales of the product are now over a billion dollars annually. Taste tests of aspartame show it to be from 100 to 200 times as sweet as sugar; this amount of variation among testers is common in taste tests for sweeteners. The calorie content of aspartame is about the same as an equal amount of sugar, but since so much less is needed, it is a low-calorie alternative to sugar. Aspartame is made of two amino acids, aspartic acid and phenylalanine, linked together by a peptide bond. Since these are amino acids present in proteins, aspartame has been regarded as perfectly safe, with one exception. Persons with PKU, an inherited disease, lack an enzyme required to metabolize phenylalanine, and must avoid that amino acid. Though aspartame has passed routine screening tests, more sophisticated tests of the effect of aspartame on concentrations of certain neurotransmitters in the brain indicate that aspartame ingestion may have significant effects on brain activity. Aspartame can be hydrolyzed, or broken up into its component amino acids in the presence of water, and undergo other decomposition reactions as well under conditions of high heat or high pH. Hence, it is not useful in cooking. It is stable under acid conditions such as in soft drinks, where the pH is often 4.5 or lower.

Alcohols with three or more -OH groups (polyhydric alcohols) are often used as humectants, or additives that keep food from drying out. Examples of these humectant compounds are mannitol, sorbitol, glycerol, and xylitol. The action of these alcohol compounds as humectants is straightforward and familiar to us: their -OH groups form hydrogen bonds with water, and this strong intermolecular attractive force keeps the water in the food. There is a bonus to these alcohols as food additives, as they have a sweet taste. Xylitol and sorbitol are used in sugarless chewing gums, because bacteria cannot ferment them to form plaque acids, and in diabetic foods, because they are metabolished slowly, and so do not raise blood sugar levels. Though they are metabolized differently, they have the same caloric value as sugar, and so do not qualify as low-calorie sweeeneners. Sorbitol has the added disadvantage of a laxative effect when eaten in quantity.

Texture Agents: Seaweed in Ice Cream

Texture is an important property of foods; a smooth, creamy ice cream is more satisfying than a thin, watery one. Gravies, frostings, and sauces are all expected to have a creamy texture or "mouth feel," and even soft drinks sweetened with saccharin feel thin compared with those sweetened with sugar. Consumers are increasingly wary of foods with a high fat or sugar content, and so texture agents have become increasingly important in prepared food formulations. Prominent among these are natural substances that have long been used in foods as texturizers, the plant polysaccharides known as gums. Seaweeds are the source of carageenan, algin, and agar, while trees and seeds provide acacia, tragacinth, locust, and guar. In studying carbohydrates we learned that humans can digest some polysaccharides, like starch, but not others, like cellulose, and this is true of gum polysaccharides as well. Guar gum, for example, is digested, while agar is not.

Fats: saturated, unsaturated, and synthetic

Lipids, the non-water-soluble compounds like fats, fatty acids, and cholesterol, have been the focus of dietary concern for over twenty years, since high blood cholesterol levels were first associated with heart disease. Long-term studies of human populations as well as animal studies have confirmed this link between heart disease and high blood cholesterol levels, but dietary recommendations have shifted away from a focus on cholesterol content in the diet toward fat content. It appears that the level of cholesterol in the diet is not necessarily related directly to blood cholesterol level, nor is cholesterol in itself a harmful substance. The body needs cholesterol to make hormones and other essential body chemicals; we have seen in Chapter 15,"Biochemistry: the Chemicals of Our Bodies" how cholesterol and the male and female hormones belong to the closely related group of chemicals called steroids. If the diet is too low in cholesterol, the body can synthesize it. The problems with cholesterol arise when it becomes deposited on the walls of arteries; the result is the formation of plaque, a waxy formation on artery walls which narrows the artery channels, increasing the work load on the heart.

Both the amount of fat consumed and the type of fat are important dietary factors affecting blood cholesterol levels. Unsaturated fats, those with double bonds in the fatty acid hydrocarbon chains, appear to increase the concentration of a type of protein called high density lipoproteins, or HDLs. These are water-soluble proteins which have the ability to associate with the cholesterol, thus carrying it into the bloodstream for use in the body instead of favoring its deposition on artery walls. Other lipoproteins, called low-density lipoproteins or LDLs, favor deposition of cholesterol and the formation of plaque; saturated fats in the diet appear to increase LDL concentrations in the blood. Thus nutrition authorities recommend that consumers choose unsaturated fats like olive oil and peanut oil over saturated fats like coconut oil, butter, and animal fats.

Fish oils are particularly recommended as a part of the diet because it is believed that is effective in preventing hardening of the arteries, and thus prevents heart attacks. This effect was first noticed in the 1970's in a study of Eskimos living in Greenland, whose diets are heavy in animal fat, but also high in fish. Like other links between diet and disease prevention, the link between fish oil and

health has a chemical basis. In Chapter 15 we saw that the essential fatty acid linoleic acid is used in the body to make prostaglandin E_2. Instead of having a double bond six carbons from the end (starting at the end opposite the carboxylic acid group) like linoleic acid, they have a double bond three carbons from the end (as well as a number of other double bonds in these polyunsaturated molecules). Fig. 18-X shows the chemical structures of eicosapentaenoic acid and decosahexaenoic acid. These fatty acids, called N-3 fatty acids because of the position of the first double bond, seem to compete with linoleic acid in prostaglandin synthesis, resulting in lowered concentrations of thromboxane, the prostaglandin that plays a critical role in blood clotting by making blood platelets more sticky. This mechanism was first proposed when it was observed that the Greenland Eskmos bruised easily. Since the accumulation of blood platelets is one of the contributors to plaque formation in arteries, it is believed that the role of fish oils in reducing thromboxane synthesis contributes to the lowered rate of heart attacks in Greenland Eskimos.

Fig. 18-X. Structures of two fish oils, prominent in the diet of Greenland Eskimos.

$$CH_3CH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH_2CH_2COOH$$

icosapenteneoic acid

$$CH_3CH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH=CHCH_2CH_2COOH$$

decosahexeneoic acid

Research on the role of lipids in the diet continues, both in long-term studies of human diet and its consequences like the study of the Greenland Eskimos, and in the laboratory where the chemical structures of the compunds in our bodies and their complex interactions are unravelled. While the final chapter in research has yet to be written, evidence mounts that a diet high in fats in implicated not only in heart disease but in other degenerative diseases like breast cancer and colon cancer, and in obesity, which carries with it a number of health risks. Currently, the average American eats about 35 to 40% of daily calories in the form of fat, and dietary recommendations are that this proportion be reduced to 30% at most. Pressures to reduce fat content in the diet have led to the development of chemical substitutes for fat, which are intended to produce similar properties of texture and "mouth feel" to those of high-fat foods like ice cream.

What's in Those Low-Fat Products?

When starches are mixed with water, they can form gels which mimic the texture and bulk of fats. Since starches have a lower calorie content than fats, and since the starch/water gels are from 70% to 75% water, the gels are a low-calorie alternative to fats. Gums, like guar gum, are used in baked

goods made with these starches to help add body and retain moisture in the product. Chemical manufacturers are also producing cellulose products that, like starches, mix with water to form gels. Since cellulose is not digestible, these compounds add no calories to foods. Proteins can be used as fat substitutes as well; when processed as small particles, proteins give a creamy texture to foods, while being less calorie-dense than fat. Simplesse, marketed by the Monsanto Corporation, is a protein-based fat substitute that is available in two formulations, one made from egg white and milk proteins, and one made from milk-derived whey protein. As we have seen, none of these types of chemical compounds have structures very much like those of fats, and they present a challenge to food manufacturers who want them to mimic fats. Particle size seems to be an important variable; particles of about a micrometer in size give a creamy texture, while smaller particles seem watery, and larger ones seem powdery or gritty. Gels behave differently from fats on heating and on mixing with other ingredients,, and so product recipes have to be specially designed for these products.

What's Left to Eat?

After reading about the ingredients in much of today's food, it may seem that none of this seems very palatable. But remember, there is an alternative to the processed food that is so prevalent today. Fresh foods are free of these added ingredients; an apple may have no label, but it is full of chemical compounds that have been shown to produce optimal health as well as taste. If the apple is organic, you may be sure that your body is gaining all the advantages of matter cycling in the biosphere, with the macronutrients and micronutrients your body needs.

PROBLEMS TO SOLVE USING CONCEPTS, FACTS, AND DECODING SKILLS FROM CHAPTER 18

1. What causes food to spoil? Explain how refrigeration affects spoilage. Explain how freezing affects spoilage.

2. a. What is osmosis?

   b. How do jams and hams use the principle of osmosis to kill bacteria?

   c. What is the chemical compound found in such concentrated form in jam that it can kill bacterial cells using the principle of osmosis?

   d. Name some chemical compounds in ham that serve this purpose.

3. Until a few years ago soft drinks contained sodium benzoate as a preservative. Then consumers complained, some because they were on sodium-restricted diets, and others because they thought drinking a beverage high in sodium was making them thirstier, rather than quenching thirst. Now most soft drinks are labelled "low sodium" because they contain potassium benzoate instead of sodium benzoate. Do you think the change affects the preservative qualities of the additive? Explain your answer.

4. Why are nitrites added to foods? Why are they considered potentially unsafe as food additives? What kinds of foods contain nitrites?

5. Vitamin C is not useful as an antioxidant in fats because it is water-soluble, not fat-soluble.
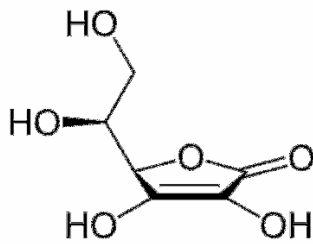
 What functional group do you think is most responsible for attracting water to the Vitamin C molecule?

Vitamin E (tocopherol)is not water-soluble, but is fat-soluble. Explain.
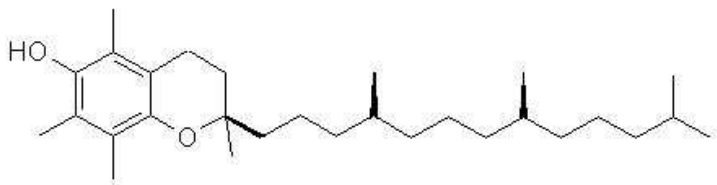
6. Virgin olive oils that have not undergone heating contain a natural anitoxidant which protects them against rancidity. From the list below, which do you think it is likely to be? Explain your reasoning.

> A. butylated hydroxyanisole
> B. butulated hydroxytoluene
> C. tocopherol
> D. ethylenediamine tetracetic acid

7. In the structure of the EDTA complex ion which appears below, circle and label the parts which indicate these parts of the structure:
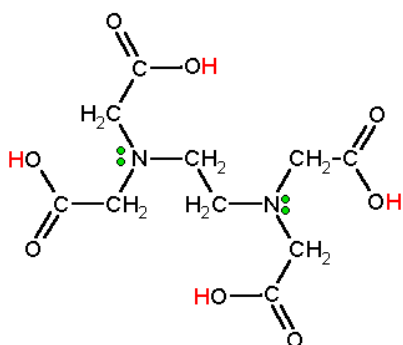

> a. the amine groups
> b. The acetic acid groups

8. Though saturated fats, those with no double bonds in the carbon chain, are known to be the least healthful type of fats, they are by far the most common type in packaged baking mixes with a long shelf life. What do you think is the chemical reason for this fact?

9. If you were employed by the starship Enterprise to design its food replicator, could you design a chemical recipe for strawberries? For cooked chicken? Explain how.

10. One of the compounds which contributes to the aroma of cooked chicken is 4-cis-decenal, the

structure of which is drawn below.
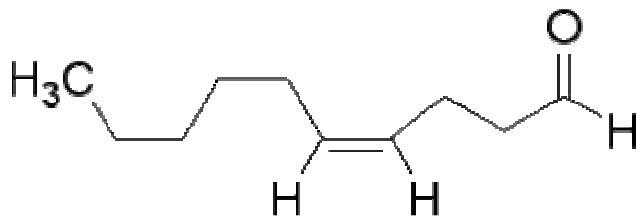
Draw the structure of its isomer. 4-trans-decenal.

10. A diet soda label reads as follows: Carbonated water, caramel color, aspartame, phosphoric acid, potassium benzoate, natural flavors, citric acid, caffeine. What do you think is the purpose for each of these ingredients?

11. A yellow jelly bean contains a food dye – at what wavelength is this compound absorbing?.