CHAPTER 1

WHAT ARE CHEMICALS?

The word *chemical* has become a dirty word in our modern American vocabulary. Our public media provide us daily with advice or warnings about the presence of chemicals in our food, air, and water and the harm they are doing to us and the world we live in. As a result, the word *chemical* conjures up visions of damage, debility, disease, and death in the minds of many people. In order to understand the threats posed by chemicals—a prerequisite to wisely protecting ourselves and our environment from their adverse effects—we must clarify or reform our concept of *chemical*.

ATOMS AND MOLECULES

All matter is composed of chemical elements. An individual unit of an element is called an atom. Atoms are the basic building blocks for all substances. Approximately 90 different kinds of stable elements are found in nature. Examples of elements are hydrogen, oxygen, carbon, nitrogen, gold, and silver. A complete listing of all of the elements, including those that are unstable (radioactive), can be found in any good dictionary. The periodic table gives detailed information about all the elements and the relationships among them. A multicolored diagram of the periodic table and an explanation of how this table is constructed can be found at the Los Alamos National Laboratory Web site (http.//periodic.lanl.gov) or the University of Sheffield Web site (www.webelements.com). Appendix A describes the concept of Avogadro's number and molecular weights for those who might be interested.

When two or more atoms (usually of different elements) are linked together by chemical bonding, they form units called molecules. A substance composed of molecules all of the same kind is called a compound. Water, salt, and sugar are examples of compounds. The number of different kinds of molecules that can be formed by the combination of from two to many thousands of atoms, from more than 90 different elements, is astronomical. Figure 1-1 shows the structures of a very simple and a very complex

The Dose Makes the Poison: A Plain Language Guide to Toxicology, Third Edition.
By Patricia Frank and M. Alice Ottoboni

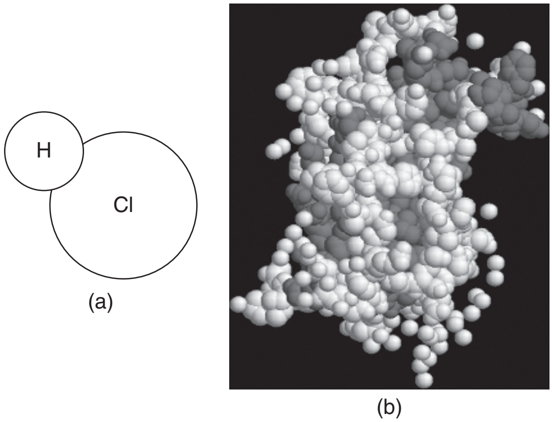

FIGURE 1-1 (a) Hydrochloric acid, a simple compound; (b) growth hormone, a complex compound. [Part (b) from Wikimedia open source, http://commons.wikimedia.org.]

molecule. All substances are composed of chemical and physical combinations of atoms (elements) and molecules (compounds). Thus, everything in our physical world is chemical—the food we eat, the water we drink, the clothes we wear, the medicines we take, the cosmetics we use, the plants in our garden, our furniture, our homes, our automobiles, and even ourselves. Our entire physical world is composed of chemicals.

NATURAL CHEMICALS

The total number of chemical compounds in our universe that occur naturally will never be known exactly, but, from the millions that have been identified thus far, we know that the total number is huge. Natural chemicals may be organic (i.e., containing carbon) or inorganic. Our inanimate world is an inorganic world. It is composed of a great number of mineral substances in which all of the elements, except for a few radioactive elements that have been created by nuclear scientists, are represented.

Our living world is composed primarily of organic compounds, the diversity of which is tremendously greater than that in our inorganic world. The number of natural organic compounds that has been identified thus far, although very large, is probably negligible compared to the number of those yet unidentified. Many of these as-yet-unidentified organic chemicals—components of the trees, shrubs, and other plants of the rain forests—could well be of great value to medical and pharmaceutical sciences.

One small segment of our organic world, food plants and animals, provide us with the nutrients that we use to build and repair our bodies. However, the plants and animals we use for food contain many more natural chemicals than just the nutrients we require. Since it is impossible to separate nutrients from non-nutrients in our foods, we depend on our bodies to do this work for us. There are many kinds and quantities of nonnutrients in our foods, particularly our plant foods. The animals we use for food have already done the job for us of selecting nutrients and eliminating most of the nonnutrients from plants.

Among the natural chemicals that we eat, many can cause adverse effects if consumed in excess. In fact, there is probably no food that does not contain some potentially harmful natural chemical. This fact is the basis for an annual project of the American Council on Science and Health (ACSH).* Every fall the ACSH publishes a typical Thanksgiving menu accompanied by identification of the naturally occurring toxic or carcinogenic chemicals present in each food on it (found at www.acsh.org). For example, taken from the 2009 menu are heterocyclic amines, acrylamide, benzo(a)pyrene, ethyl carbamate, dihydrazines, d-limonene, safrole, and quercetin glycosides—and this just from the turkey with stuffing! If you are keeping to a vegetarian diet, then the 2009 menu shows salad may contain aniline, caffeic acid, benzaldehyde, hydrogen peroxide, quercetin glycosides, and psoralens.

An interesting method for ranking the potential health effects from exposure to such toxicants that occur naturally in foods was developed by Bruce Ames and his colleagues at the University of California, Berkeley. Dr. Ames has written numerous articles for both scientific and popular publications reviewing the subject of naturally occurring toxicants and their carcinogenic hazards. Rankings are based on data from the scientific literature as well as from Dr. Ames's own laboratory, using accepted methods of risk assessment. These rankings are one approach to the evaluation of relative health risks posed by suspected carcinogens, both natural and synthetic.

SYNTHETIC CHEMICALS

Humans, in their ingenuity, have been able to take the basic building blocks of which all matter is composed and link them together in new combinations to produce compounds not found in nature. Thus, we have a host of synthetic substances, primarily organic, available to us, which we put to a seemingly endless variety of uses—pharmaceuticals, pesticides, and polymers of all sorts, including the common household plastics with which we are so familiar.

* A list of abbreviations can be found at the end of the book.

The term *organic* has been extensively used by the health-food industry to mean one thing and used by chemists to mean another; as a result, the term is generally misunderstood by the public. *Organic* has come to mean something (usually food) that is naturally occurring or produced without the use of pesticides or other synthetic chemicals, such as hormones. Scientifically, organic chemicals are simply chemicals composed primarily of the element carbon, independent of whether they are natural or synthetic. It comes as a shock to many people that almost all synthetic chemicals, including pesticides, are organic chemicals. The term *organic* was coined long before the birth of modern chemistry.

Early scientists who studied the composition of matter recognized that substances produced by living organisms were different from all other chemicals then known to humans. They called the former *organic* (derived from organisms) as opposed to the latter, which they classified as *inorganic*. Early in the nineteenth century, scientists discovered that the element carbon was present in all organic compounds; hence carbon chemistry became synonymous with organic chemistry.

The great complexity of carbon chemistry, relative to inorganic chemistry, the large size and complicated structures of many organic compounds, their great number and variety, combined with the fact that organic chemicals were found only in living organisms or products of living organisms led the early-day chemists to endow organic chemicals with mystical properties. They considered that the laws that governed the behavior of inorganic chemicals did not apply to organic chemicals; humans could synthesize—that is, manufacture—compounds such as nitrous oxide and hydrochloric acid but were incapable of synthesizing organic compounds in the laboratory at that time.

The special properties of organic chemicals were attributed to the action of a supernatural force, the "vital force," as distinct from the crude and vulgar forces that governed inorganic chemicals. Jöns Berzelius, a noted chemist of the early nineteenth century, wrote that the vital force was unrelated to inorganic elements and determined none of their characteristic properties. Berzelius considered that the vital force was a mysterious property beyond comprehension.

The birth of synthetic organic chemistry occurred at about the time of Berzelius's writing, with the first laboratory synthesis of an organic chemical, using basic chemicals as starting materials. The first synthetic organic chemical was oxalic acid, made by the German chemist Friedrich Wohler. A short time later in 1824, Wohler also synthesized urea. After this accomplishment, Wohler wrote to Berzelius to tell him that he had prepared urea, a chemical found in the urine of animals, "without requiring a kidney or animal, either man or dog."

The notion that organic and inorganic chemicals were qualitatively different persisted for decades after the revolutionary demonstration that humans could, indeed, synthesize organic chemicals. The science of chemistry was greatly retarded until the chemical properties of carbon and its place in the periodic table were more fully understood. The great numbers of synthetic organic chemicals that have been created since the end of World War II were not of much public interest until the publication of Rachel Carson's book *Silent Spring* in 1962. This book stimulated great interest in the effects of pesticides on environmental and public health and brought to public attention the proliferation of chemicals.

The number and variety of synthetic organic chemicals are truly amazing. In 1978, the American Chemical Society's registry of chemicals listed over 4 million organic and inorganic chemicals; of this number, more than 95 percent were organic. Of all the known organic chemicals, perhaps half are naturally occurring chemicals that have been synthesized in the laboratory or isolated from natural sources. Between 1965 and 1983, 6 million additional chemicals had been produced, and the rate of synthesis has only increased since then.

For the average person, what is the significance of the existence of these millions of chemicals? Among those that are not naturally occurring, a great many exist only in small quantities in vials on chemists' benches or in chemical storerooms. They have not been found to have any practical use or function, and so they have not been developed commercially—yet. However, with the advent of high-throughput screening techniques where robotics speed up the screening process, many thousands of chemicals can be rapidly analyzed for their ability to bind to various animal and human chemical receptors. Out of this screening, chemicals that were once thought to have no value are being identified as potential medicines and pesticides and for other human uses.

The toxicity of synthetic chemicals—that is, the degree to which they are poisonous—covers the entire range from essentially nontoxic to extremely toxic. This is also true of inorganic compounds (think water and arsenic). Some synthetic chemicals, such as artificial sweeteners, are edible, whereas others, such as chemical warfare agents, are lethal in extremely small amounts. Regardless of the degree of toxicity, the principles of toxicology apply equally to all chemicals, whether synthetic or natural, organic or inorganic.

The number of chemicals that actually enter homes is not known, but a survey of the wide variety of products found in the home setting—such as cleansers, polishes, drugs, cosmetics, prepared foods, pesticides and other garden chemicals, automotive products, and hobby products—suggests that it is quite large. Despite the wide variety of products, many contain the same basic chemicals. Thus, the actual number of individual chemicals that the average person comes in contact with in home products is probably much closer to several thousand rather than several million. The majority of chemicals that enter homes are not harmful when used properly, but some are treated with a more cavalier attitude than is warranted, as witnessed by the numerous accidental poisonings that occur in children.

The people in contact with the widest variety of potentially dangerous chemicals are those in businesses or professions that use chemicals in some process or procedure and those who work in industries that synthesize, manufacture, formulate, or use chemicals to make other products. Few of these chemicals find their way into a home setting.

CHEMICAL CATEGORIES

We categorize chemicals in many different ways, the broadest of which is whether they are natural—produced by a living process—or synthetic—made by humans. Other ways we classify chemicals are by the use we make of them (foods, drugs, pesticides, etc.), how they are physically organized (solid, liquid, gas), what kind of animal they are (fish, reptiles, birds, mammals, etc.), whether they are organic or inorganic (animal, vegetable, or mineral), and so forth. Plant and animal probably were two of the earliest categories recognized by humans. Plants stayed put, whereas animals usually moved about freely. Based on this classification, corals were considered plants for many years until their animal nature was discovered.

A scheme of classification by the use we make of a chemical or product is essential for government regulation of such items as foods, drugs, cosmetics, pesticides, industrial chemicals, and medical devices. If a substance is claimed to be a food, it is governed by the food laws. If the exact same substance is packaged and labeled a drug, it is governed by the drug laws, not by the food laws. The laws that pertain depend on what use the manufacturer or seller specifies for the product. For example, hydrochloric acid is regulated as a household product when it is present in cleaning compounds, as a drug when it is used to treat people with low gastric acidity, as a hazardous industrial chemical when it is used in electroplating, and as a antibacterial adjuvant when it is used to enhance the germicidal activity of chlorine in swimming pools. Hydrochloric acid is natural when produced by the stomach and synthetic when made in the laboratory. Interestingly, all things tobacco are regulated by the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF), but since 2009 the Food and Drug Administration (FDA) is monitoring the advertising and content of cigarettes, emphasizing the toxic nature of cigarette ingredients and smoke. (The ATF was originally part of the Department of the Treasury and was primarily concerned with collecting revenue generated by taxes on the items it regulated. ATF still is involved in investigating the smuggling of cigarettes.)

Another example is boric acid, which occurs naturally as the mineral sassolite but also can be synthesized in the laboratory. It is regulated as a household product when used in laundry detergents, as a drug when sold as an antiseptic eyewash, as an insecticide when used to kill roaches, as an herbicide when applied to kill weeds, and as a flame retardant when used to fireproof fabrics. Many chemicals, such as hydrochloric acid and boric acid, fall into both drug and pesticide categories. Coumarin compounds, such as warfarin, are not only excellent rodenticides but are also valuable anticoagulant drugs that are used to prevent blood clots. Dichloro diphenyl dichloroethane (DDD), a close relative of dichloro diphenyl trichloroethane (DDT)—the infamous pesticide now banned in the United States—and itself an insecticide, was once used therapeutically to treat certain forms of adrenal cancer.

The important lesson to be learned from these examples should be apparent: The physical, chemical, and toxicologic properties of any chemical are totally independent of the category in which it is placed. The toxicity of boric acid is exactly the same when it is used as a drug as it is when it is used as a pesticide.

Although people are concerned about the products and effluents from the chemical industry, the class of man-made chemicals that is almost universally of concern is the category known as pesticides. Pesticides are substances, natural or synthetic, that are used to kill a plant, animal, insect, or other organism that has been determined to be undesirable for some economic, medical, or esthetic reason. Included in the pesticide category are insecticides, fungicides, herbicides, rodenticides, germicides, and a whole host of other "-cides."

Countless chemicals are as toxic or more toxic than many of the pesticides, but the focus of fear centers on this group. Why? One reason is the tremendous amount of publicity given to reports of damage from the presence of pesticides in our environment and even in our own bodies. Another reason is that pesticides are used to kill living things and thus are labeled as poisons in the public mind. The concept of poison is considered by many people to be an all-or-none phenomenon: A chemical is either a poison or it is not, with no shades of gray in between. Nothing could be further from the truth. Such simplistic reasoning is counterproductive to an understanding of how and why chemicals cause harm. It also points up the fallacy of assigning blanket judgments of safety or harm to categories of chemicals.

CHEMICALS: "GOOD" AND "BAD"

A common misconception that must be overcome before an understanding of toxicity can be achieved is that chemicals made by nature are good and those made by humans are bad. Actually, toxicologists recognize that Mother Nature is far more ingenious than humans could ever be in devising toxic chemicals; it is also much more prolific. Of all the chemicals, the number of natural ones far exceeds the number made by humans. In addition, there are tens to hundreds of thousands of plants that botanists have not yet identified, much less characterized chemically. The voluminous literature on the toxic properties of naturally occurring chemicals that have been identified in food and nonfood plants, animals, and microorganisms supports an estimate that the fraction of natural chemicals that are toxic is at least as great as the fraction of synthetic chemicals that are toxic.

Some of the most toxic chemicals are produced by living organisms. A good example is botulin, the toxin produced by *Clostridium botulinum* organisms. One milligram (mg) of botulin (128 thousandth of an ounce) is capable of killing 20 million mice. It is estimated that the average oral lethal dose of botulin for an adult human is about 1 nanogram (ng) with one tablespoon containing enough toxin to kill over 3 *billion* people. Botulin toxin is available commercially as the active ingredient in prescription wrinkle injections (Botox® and others), and other medical uses have been found for it, including treating overactive bladder in children and treating muscle spasms. Studies have even been conducted for its efficacy in treating Parkinson's disease. So although botulin is a very toxic compound, it has beneficial uses for humans when used correctly.

Since we will be using a variety of measurements in the metric system, Table 1-1 introduces these units. When we refer to the concentration of a chemical in the air or solution, we use the units presented in Table 1-2.

Toxic chemicals of natural origin, such as those produced by algae and other microorganisms, snakes and other venomous animals, and plants, constitute a common threat to wild and domestic species. Actually, natural and synthetic chemicals together are probably far less detrimental to wildlife species than habitat destruction resulting from encroachment by civilization and the burgeoning human populations.

TABLE 1-1: Common Units

Metric Unit	Abbreviation	Equivalent to:
kilogram	kg	1,000 g, 1 million mg, 2.2 lbs
gram	g	1,000 mg, 1 million µg, ~0.035 oz
milligram	mg	1,000 µg, 1 thousandth of a g
microgram	µg	1,000 ng, 1 million pg
nanogram	ng	1 billionth of a g
picogram	pg	1 trillionth of a g
liter	L	~1 quart, ~33 oz
pound	lb	16 oz, 454.5 g, 0.45 kg
ounce	oz	28.4 g

TABLE 1-2: Common Concentrations

Concentration	Abbreviation	Equivalent to:
milligram/kilogram	mg/kg	ppm, pg/g
microgram/kg	µg/kg	ppb, ng/g
nanogram/kg	ng/kg	ppt
milligram/liter	mg/L	ppm
parts per million	ppm	mg/kg, µg/g
parts per billion	ppb	µg/kg, ng/g
parts per trillion	ppt	ng/kg

Although man-made chemicals form a far smaller group than natural chemicals, they have become the symbols for the damage that the human species is inflicting on planet Earth and all its inhabitants. Why have synthetic chemicals been singled out for this distinction? One reason is that humans have been irresponsible, often unknowingly, in their use and disposal of synthetic chemicals, which are the relatively new products and tools of our civilization. As a result, problems of air, water, and general environmental pollution have been visited on societies throughout the world. Further, because synthetic chemicals are created by humans, there is a sense that they can be controlled by humans. The synthesis of new chemicals can be prevented, and the production of old chemicals can be halted.

A second reason relates to the general feeling that natural chemicals pose no threat. The theory is that humans and animals evolved with natural chemicals and are therefore adapted to them. This theory is not in accord with known adverse effects of natural chemicals in humans, such as the carcinogenicity of certain mold toxins or the acute toxicity of chemicals produced by a variety of microorganisms.

WHY THE "GOOD-BAD" DICHOTOMY?

What are the properties of synthetic chemicals that have fostered the dichotomy of man-made (bad) versus natural (good)? An exploration of this question is important to an understanding of the effects of chemicals on living organisms. The attributes of synthetic chemicals that set them apart from chemicals of natural origin were elegantly described years ago by the American biologist Barry Commoner:

> The clash between the economic success of synthetic petrochemicals and their increasing vulnerability to biological complaints is the inevitable result of the fact that they are synthetic-made by man, not nature. In every living cell there is a tightly integrated network of chemical processes which has evolved over three billion years of trial and error. In all of the countless organisms that have ever lived over this time, and in all of their even more numerous cells, there have been a huge number of opportunities for chemical errors—the production of substances that could disrupt the delicately balanced chemistry of the living cell. Like other evolutionary misfits, any organism that made these chemical mistakes perished, so that the genetic tendency to produce the offending substance was eliminated from the line of evolutionary descent. One can imagine that at some point in the course of evolution some unfortunate cell managed to synthesize, let us say DDT—and became a casualty in the evolutionary struggle to survive.
>
> Another requirement for evolutionary survival is that every substance synthesized by living things must be broken down by them as well be biodegradable. It is this rule which establishes the distinctive closed cycles of ecology. When petrochemical technology synthesizes a new complex substance that is alien to living things, they are likely to lack the enzymes needed to degrade the substance—which then accumulates as waste. This explains why our beaches have become blanketed in debris, since non-degradable synthetics have replaced hemp, cordage, wooden spoons and paper cups, which, because they were made of natural cellulose, soon decayed.
>
> The likelihood that a synthetic organic chemical will be biologically hazardous increases with its complexity; the more elaborate its structure, the more likely that some part of it will be incompatible with the normal chemistry of life.
>
> —The promise and peril of petrochemicals,
> *New York Times Magazine*, September 25, 1977, p. 38.

We can distill from this essay three attributes that make man-made chemicals biologically undesirable:

1. They are made by humans, not nature.
2. They are not biodegradable.
3. They tend have very complex structures.

None of these attributes bears any relationship to toxicity or the ability of a chemical to do harm. Let us examine each attribute individually to understand why this is true.

Man-made Chemicals Are Made by Humans

The first attribute—man-made chemicals are harmful because they are made by humans—is a commonly held opinion. It is an example of a form of reasoning that in logic is known as *circulus in probando*, or, literally, "a circle in the proof." Water is wet because it is water, man is human because he is man, and truth is good because it is truth are examples of circular reasoning. Such logic adds nothing to the argument that synthetic chemicals are biologically damaging. It returns us to the dichotomy of man-made (bad) versus natural (good) without adding anything to our knowledge of why the dichotomy exists or of its validity.

The hypothetical cell described above as perishing in some eon past because it committed the blunder of synthesizing DDT, a complex man-made organic compound with insecticidal properties, is worthy of a moment's reflection. This unfortunate cell is intended to serve as a dramatic, and perhaps whimsical, example of the undesirability of synthetic chemicals. However, the lamentable cell could never be more than a creature of fiction because its tale is founded in fancy rather than fact. The reality is that living cells do not just suddenly synthesize highly complex molecules. Complex natural molecules are the end product of many biochemical reactions occurring in well-coordinated sequence.

The building of a complex molecule by a living organism may be likened to the building of an automobile on an assembly line. At each step along the way, some small change or addition is made until finally, at the end of the line, an automobile emerges. So it is with complex biochemicals; each reaction in a biochemical chain makes some small change or addition to the molecule produced by the preceding reaction. This process is repeated numerous times, with each reaction producing the precursor for the next reaction in the chain, until a complex biochemical molecule is synthesized.

If all intermediary precursor biochemicals are compatible with cellular life, it is highly unlikely that the final step in the synthesis would produce a biochemical lethal to the cell. Thus, if the hypothetical cell described earlier did manage to synthesize DDT, it probably would be unaffected by the presence of DDT within itself. If the unfortunate cell were a plant cell, its destiny might be radically changed. Consider the tremendous survival advantage that a built-in insecticide would confer on a plant! The idea of a plant cell producing an insecticidal chemical is not as absurd as it may seem on the surface; pyrethrins and nicotine, produced by chrysanthemums and tobacco, respectively, are commercially available insecticides, and they function in the plant to control external pests.

The concept that chemicals are good or bad depending on their origin (nature or the laboratory) requires that chemicals possess an inherent moral quality of "goodness" or "badness," which, of course, is not true. Morality is a creation of the human mind and applies only to human conduct, not to inanimate things such as chemicals. The anthropomorphic view that nature, evolution, living cells, or inanimate objects are endowed with human sensibilities is out of context with reality. Such a view of cellular functions or natural processes is common among primitive cultures and medicine men. Scientists and authors may use the term *Mother Nature*, or credit natural processes with intelligence as a figure of speech for literary effect, but they do not invoke the gods to explain phenomena outside their areas of scientific expertise.

The distinction between natural and man-made chemicals is actually a man-made distinction. Living cells are not conscious units capable of deciding whether molecules that enter them are natural or synthetic. Our bodies cannot recognize the origin of a chemical—Mother Nature or the chemical laboratory. Our bodies can distinguish only between molecules they can use (for energy or to make more of themselves, more muscle, more bone, more blood, etc.) and molecules they cannot use.

Biochemicals may be natural or man-made, and foreign chemicals (xenobiotics) may be natural or man-made. The distinction between biochemicals and foreign chemicals exists for all living organisms and varies among classes of organisms. What may be a biochemical for one class of living things may be a foreign chemical for others. For example, strychnine is a natural chemical produced by *Nux vomica* plants. Thus it is a biochemical for *Nux vomica* plants but a foreign chemical (and a deadly one at that) for animal species, including humans. Although strychnine is a very toxic chemical for many species for which it is foreign, foreign chemicals are not of necessity harmful. The toxicity of chemicals does not correlate with their origin. Both natural and synthetic chemicals have wide ranges of toxicity, with large areas of overlap.

Man-made Chemicals May Not Be Biodegradable

The second attribute of man-made chemicals that allegedly makes them undesirable is their lack of biodegradability. *Biodegradation* refers to the process by which living organisms break down (metabolize) complex molecules to simpler molecules so that they can be eliminated by the body. In actual fact, there are relatively few man-made compounds that are not metabolized to some degree by some living organisms. All higher animals, including humans, have very complex sets of enzyme systems that process xenobiotic chemicals. These enzymes found primarily in the liver are referred to as the cytochrome P450 metabolizing enzymes. Among the synthetic compounds that are most resistant to biodegradation are the long-chain polymers that we know as plastics. As a class, the plastics are nontoxic. In fact, some are sufficiently inert biologically to be implanted surgically as substitutes for blood vessels, bone, and other living structures.

There are some substances produced in nature that are as resistant to biodegradation as synthetic polymers, such as the skeletons of diatoms, sea shells, bones, and hair. Thus, the bones of prehistoric humans and animals can be studied by archeologists today, thousands and thousands of years after their owners walked on Earth. And Napoleon's hair was still intact 140 years after his death, available to chemists for arsenic analysis to test the theory that he died of arsenic poisoning.

Chemicals, both natural and synthetic, that are resistant to biodegradation may be either toxic or nontoxic. If they are toxic, they enter the organism and may do damage because they are not converted to a less toxic form. If they are nontoxic, they enter and do no damage because they are not converted to a more toxic form via the metabolic pathways. In both cases, they are essentially unchanged by their passage through the organism. Chemicals, both natural and synthetic, that are biodegradable may also be either toxic or nontoxic. Some that are themselves nontoxic may be converted into toxic compounds during the process of metabolism, although this is relatively rare as the metabolism of xenobiotics *usually* leads to less toxic forms.

For these chemicals, biodegradability is a disadvantage to an organism; the process of biodegradation produces toxins. Other chemicals that are themselves toxic may be metabolically converted to less toxic or nontoxic compounds. For these chemicals, biodegradability is an advantage, and the process is called detoxification. Biodegradability and toxicity are independent properties of chemicals.

Nonbiodegradable junk may offend our esthetic senses when it clogs our beaches in debris, but plastic spoons and cups are no more esthetically offensive than wooden spoons and paper cups, which, if not picked up and discarded, have a long residence time as junk. If industry's successes in making biodegradable plastics widespread becomes a reality, the plastic counterparts may soon become more quickly degradable than paper or wood.

Most foreign objects, whether they are made of natural or synthetic materials, have the potential to harm any creature that ingests, inhales, or becomes entangled in them. The damage that has been done to some marine birds and mammals by plastic objects relates primarily to the form or shape of those objects. Children who play with thin plastic bags are also at risk if they put the bags over their heads and faces; they may suffocate because the plastic film does not permit air exchange. Plastic bags themselves are generally inert, but they can cause physical damage and even death.

Biodegradable plastics may not solve the ecological problem completely. A seal pup with its mouth held shut by a six-pack ring cannot wait a few months or even a few weeks for the ring to decompose. Changes in design of containers and packaging may be required as well as changes in the composition of the materials used. However, the problem of plastic litter is as much a societal problem as an industry one. We must accept the responsibility for proper disposal of debris that may harm some creature. It does not take much time to cut open six-pack rings or tie knots in plastic bags.

Further, the damage done by plastic debris to fish, fowl, and aquatic organisms, as well as to the esthetic beauty of our beaches, is small compared to that done by crude oil spilled from tankers, accidentally or deliberately, or released during blowouts from offshore wells. Crude oil, a raw material for synthetic chemicals, is not man made but produced by natural processes from once-living organisms. Some components of crude oil, all of which are natural, are notably resistant to biodegradation, as any resident of a coastal town plagued by an oil spill will attest. An example of a useful crude oil derivative that is resistant to biodegradation is asphalt, which is used to pave our streets.

A property of chemicals that results from a lack of biodegradability is persistence, the ability to remain in the environment unchanged by such factors as light, temperature, or microorganisms. Environmental concerns about persistence are related almost entirely to pesticides. Persistence is a desirable quality in pesticides, from the viewpoint of effectiveness and efficiency, since a pesticide that retains its ability to kill pests for prolonged periods need be applied less often than one that degrades rapidly. Thus, the total quantity of pesticide required to do a job is considerably less, which reduces the cost of crop protection and production.

The undesirable aspects of persistence in pesticides relate to their continued action after they are needed and to the fact that they remain in the environment for prolonged periods. The majority of persistent chlorinated hydrocarbon pesticides, such as DDT, have been banned from use in the United States because they were considered responsible for declines in the populations of certain wildlife species.

The rationale that substitution of nonpersistent pesticides for persistent ones will solve all of the environmental problems attributed to the latter is an example of the myopic thinking that permeates so many decisions relating to environmental protection. The rationale seems to be based on the notion that a nonpersistent pesticide does its job and then immediately, in a puff, dematerializes into nothingness. On the contrary, all nonpersistent pesticides merely degrade to other chemicals! The only difference is that most of these new chemicals do not have the same pesticidal action as their parent chemicals. These new chemicals may not kill pests, but what is their toxicity to other organisms? What is their fate in the environment? Do they persist? Do they accumulate?

A great deal of data indicate that some degradation products of nonpersistent pesticides have at least as much potential for nontarget damage as DDT. The identities of many of these degradation products are known because one of the requirements for registration of pesticides for commercial use is study of their environmental fate. However, there is absolutely no program for environmental monitoring of persistent products of nonpersistent pesticides. There is no demand from the groups that lobbied so hard to ban persistent pesticides to investigate the potential environmental damage from nonpersistent pesticides. Why? This is a philosophical question worthy of pursuit for anyone truly concerned about protection of the environment.

The demand for more applications of nonpersistent pesticides may result in an increased environmental burden of degradation products since the degradents themselves may be toxic. By forcing a ban on persistent pesticides, environmentalists may very well have created a much larger environmental problem than the problem they perceived as requiring the ban. Time will tell, if someone asks the right questions.

Time has already told us that the switch from persistent to nonpersistent pesticides has greatly increased the number of acute poisonings among farm workers. Cases of acute illnesses from chlorinated hydrocarbon insecticides were virtually nonexistent prior to the ban. The worst problems were cases of skin irritation. When DDT was banned, the use of organophosphate insecticides increased greatly. A large increase in poisoning of farm workers accompanied this increase; some poisonings were so severe as to be lethal. The efforts to protect wildlife had the ultimate effect of producing acute health problems among workers in the agricultural industry. Despite elaborate programs of worker protection—medical surveillance, protective clothing and cleanup, automatic measuring and mixing devices to avoid human contact, restrictions on reentry into treated fields, and so on—poisonings of farm workers by nonpersistent pesticides still occur. With the advent of a "natural" pesticide like BT (*Bacillus thuringiensis,* a bacteria that can be genetically engineered to enhance specific traits and is used to control gypsy moths), people hoped that poisonings would decrease. However, BT's usefulness is limited to certain classes of insects, and it is harmful to all butterflies and moths. Additionally, some chemically sensitive people believe that they respond just as severely to BT as to other pesticides.

Man-made Chemicals May Be Very Complex

The third attribute of man-made chemicals that presumably makes them undesirable is their complexity. Many synthetic organic chemicals do have very complex structures. The majority of synthetic chemicals are petrochemicals, which simply means that they are derived from petroleum. Petroleum is an organic substance; thus, petrochemicals are organic chemicals. Organic molecules, both natural and man made, may be very large and complex or small and relatively simple. Organic compounds are those having the element carbon in their structures. The combination of carbon atoms with atoms of other elements, primarily hydrogen and oxygen, gives rise to an extremely large group of compounds containing many subgroups with widely varying properties and uses. The orientation of the component atoms to each other is an important factor in determining the properties of the individual carbon compounds. All organic compounds, whether natural or synthetic, tend to be much more complex than inorganic compounds because of the nature of the carbon bond.

Some of the most complex chemicals that exist are those produced by living organisms, such as enzymes, hormones, and the deoxyribonucleic acid (DNA) molecules that carry genetic information. Some of these natural compounds have been synthesized in whole or in part in the laboratory. In fact, many natural organic compounds are so complicated that even the details of some of their structures remain hidden. Like nature, humans have also synthesized some very complex organic compounds, including the polymers, pharmaceuticals, and pesticides mentioned previously. With the advent of cell culture technology and the ability to insert the DNA of other species into bacterial cells, many complex hormones and enzymes can be synthesized in the laboratory. Although these are considered to be synthetic, they require the help of other organisms. The complex creations of both human and nature may or may not be toxic.

There are many relatively simple inorganic chemicals, such as cyanide and arsenic compounds, all of which may occur naturally or can be synthesized in the laboratory, that are much more toxic than complex synthetic compounds such as the drug aspirin or the pesticide malathion. Complexity and toxicity are independent properties of chemicals.

To understand what makes chemicals toxic, it is essential to recognize that the degree of toxicity of chemicals does not correlate in any way with whether they are natural or synthetic, biodegradable or nonbiodegradable, simple or complex. Arguments to the contrary, no matter how eloquently they are presented, have no basis in fact and serve only to confound the public.