WHY STUDY CHEMISTRY?

by Richard E. Dickerson

For one thing, there are blunders of the past to correct. For another—we might even find out what life is, where it came from, and how it operates.

Why study chemistry? What does a chemist do that inspires you to be one or prompts you to learn something about the field even if you do not plan to pursue it as a career? In the past, the answer has often been given in terms of the many important products that have come from the laboratory: dyes, petrochemicals, plastics, fertilizers, drugs, synthetic fibers. Older texts are filled with photographs of blast furnaces and rayon spinning mills, and eulogies to the Haber process for ammonia and the Solvay process.

A shift in values has come about in the present generation. Material comfort and a colored plastic telephone do not seem as centrally important as they once did. Synthetic rubber now hardly seems like one of the higher manifestations of the human spirit. Indeed, many of our once-heralded achievements have backfired on us. We can travel from one place to another rapidly at the cost of polluting the air and filling it with noise. We can manufacture cheap paper to support widespread literacy at the cost of killing off the water life downstream. Our hopes for abundant nuclear power are clouded by the problems of thermal pollution. We keep the wheels of transportation turning, but blacken our coastlines with escaping oil to do so. We eradicate insects to aid our crops and then find that we have also killed the robins and contaminated the salmon in Lake Michigan. The genie of chemistry seems to be a malevolent spirit who accompanies each gift with a trap that leaves us with a new problem for every one we solve.

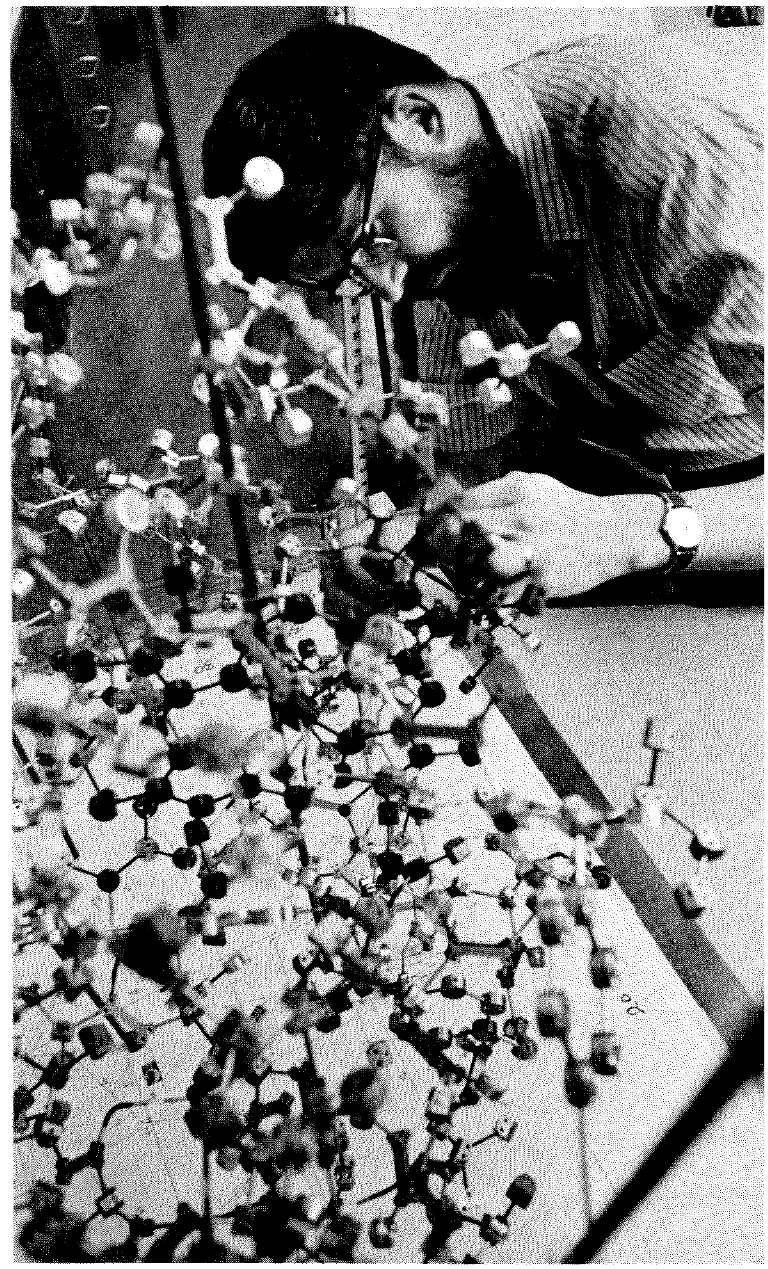
Most of these traps have evolved because we looked at each technical advance in isolation and paid too little attention to the ultimate effects of each new development. The enthusiasm of past generations for the "wonders of chemistry" was sincere but naive. The proper response is not to turn away from science, but to use it more intelligently. We desperately need a generation of scientists who are committed to the wise use of their discoveries. Moreover, we need a generation of nonscientists who know enough about chemistry and physics to anticipate the outcome of technical decisions and to compute long-range costs and benefits as well as short-term gains. There has never been a time when it was more important for the nonscientist to understand chemistry and physics, for there has never been a time when political and economic judgments were as likely to get us into scientific trouble. Perhaps in another generation the proper entry into government and politics should not be a degree in law but in general science.

A child never worries about where his home came from or who will provide his food and clothing. These things are just there, in the natural order of life. If the child leaves his room in a mess, somehow it will all be put right. We have all been living in a very small room, the planet earth. Like children, we have accepted its gifts as inexhaustible and free. We have littered our room with garbage—solid, liquid, and gaseous—and trusted that it will all disappear somewhere. Yet we are entering a troubled intellectual adolescence, in which we are realizing that these assumptions are not true. If the planet is to remain livable, someone must keep it so. There are no such things as either endless resources or infinite capacity for waste disposal. One man's garbage inevitably becomes someone else's raw materials. One of the tasks of the chemist in the coming years is to create workable plans by which we can live together on this planet, and the job of the scientifically literate citizen is to make it possible for such plans to be put into action. The Greeks were ingenious in imagining torments for their fallen heroes, but even they did not imagine Prometheus finally drowning in garbage.

So far we have been talking about what we should do with chemistry. But what can chemistry do? Just as we are beginning to look at life on this planet as a whole, so we are beginning to look at the chemistry of an entire living organism. Chemists at last are beginning to have something concrete to say about that most intricate of chemical systems, a living creature. Francis Crick, who together with James Watson discovered the molecular structure of the hereditary material of life, DNA, was a physical chemist. The deciphering of the nucleic acid code, or the system by which the information for building a living organism is stored in DNA, was a triumph of biochemists. When Arthur Kornberg and his colleagues succeeded in copying the complete DNA of a virus and in demonstrating that this synthetic genetic material would build a new virus as well as natural DNA would, they did so with the intimate cooperation of enzyme chemists and molecular biologists. Organic and biochemists are now able to synthesize vitamins, hormones, and enzymes in a way that would have seemed incredible ten years ago. Penicillin, insulin, and even the enzyme ribonuclease have been made synthetically, and the tour de force of vitamin B_{12} synthesis is on the way. Physical chemists and biochemists can solve the three-dimensional structures of enzymes and can construct atomic models of them. With these models as a starting point, enzyme chemists can make more progress than ever before in understanding how the catalytic action takes place.

The implicit purpose of knowledge in chemistry, as in any other area, is control. If we know how hormones act, perhaps we can control their action. If we understand enzymatic catalysis, perhaps we can correct metabolic failures such as phenylketonuria, in which the inability to metabolize one key substance can lead to feeblemindedness in an infant. If we learn enough about the chemistry of DNA and genetic information transmission, perhaps we can detect and cure mongoloidism, which is produced by an extra chromosome early in the life of the embryo. Even more dramatic hereditary engineering has been proposed, but we need to distinguish between the verbs "can" and "should." As R. S. Morison has said, "In a short time we will be able to design the genetic structure of a good man. There is some uncertainty about the date, but no doubt that it will come before we have defined what a good man is." ["Science and Social Attitudes," *Science*, **165**, 150, (1969)]

New examples of chemical influences—both natural and artificial—on behavior are continually coming to light. Two rare chemicals in the bloodstream have a suggestive but unproven connection with schizophrenia. Large doses of the common lactic acid can produce anxiety neuroses



Richard E. Dickerson, professor of physical chemistry.

"One of the advantages of alcohol over LSD is that the euphoria induced by alcohol is so clearly second-rate and temporary."

in humans, and the behavior-changing effects of mescaline and LSD are a matter of concern. Before LSD became a cult, it was a research tool in the study of artificial schizophrenia.

Rats are most like humans in their clannishness and their reaction to overcrowding. Their sense of community identity and their enmity to strangers is strong (one is tempted to add "and human"). Experimenters have actually brought about a reduction in the rat population of a city block area by introducing new rats. The reason, interestingly enough, is chemical. The presence of new and alien rats on the territory of an existing group leads to fighting, stress, and anxiety. But it is not the fighting that lowers the numbers of rats. When a rat is made neurotic by conflict and overcrowding, its body secretes a hormone that reduces sexual aggressiveness in males and interferes with pregnancy in females. The birth rate therefore falls, and the pressures that led to the anxiety are thereby eased. Such chemical control of behavior clearly is adaptive and advantageous, at least for wild populations of rats. Is part of our behavior similarly subject to chemical control? The answer is certainly yes. What we do about it is a tougher question. Giving everyone tranquilizers is no answer to the problem; they do not even permanently relieve the symptoms. In a sense things are more difficult when there are quick chemical responses to psychological and social problems, for they can weaken the pressures to find solutions to the real ills. One of the advantages of alcohol over LSD is that the euphoria induced by alcohol is so clearly second-rate and temporary.

In the past our control of our environment has been as haphazard and uncertain as our control of the chemistry of our bodies. The very permanence of the products of chemical technology has brought trouble. So long as we built with materials that were collected rather than synthesized, our debris stood a good chance of blending back into the environment without leaving permanent scars. Wood and cloth will rot, organic matter will be eaten by microorganisms, iron will rust, and glass will shatter and mix with the natural silicates that make up the soil. But aluminum remains intact long after iron has disappeared. Polyethylene and most other plastics will neither break up nor be eaten by microorganisms. Synthetic detergents have created foaming rivers downstream from sewage disposal plants because they cannot be degraded by bacteria in the way that soaps can. It is possible to make biodegradable detergents, but they are more expensive. At what point do we decide that the expense of these biodegradable compounds is less than the damage to the environment in terms of fish killed and streams polluted? And who pays the cost? Do we similarly regulate the use and discarding of inert materials such as aluminum and polyethylene, or do we find microorganisms to eat plastic? (This is a tough assignment. What would polyethylene-eating microorganisms have done in the millions of years before Lavoisier?)

Insecticides such as DDT have proven embarrassingly effective. Their resistance to chemical breakdown is an advantage to the farmer who wants one spraying to last a long time, but a disadvantage to the higher organisms in which the DDT concentration builds up with time to near-lethal or lethal doses. In one marsh on the Long Island shore, where spraying with DDT for mosquito control has been carried out for 20 years, the plankton have accumulated 0.04 parts per million (ppm) of DDT by wet weight. But the clams which eat the plankton have 0.42 ppm of DDT, the minnows have 1.0 ppm, and the sea gulls that eat both clams and minnows have as much as 75.0 ppm of DDT. Another tenfold increase in this concentration of insecticide in the food chain would lead to death, as it has done for smaller birds in some parts of the midwest. The hopes of Great Lakes fishermen that the introduction of Coho salmon from the Pacific Northwest would bring on a renaissance in sport fishing in the area were dimmed when the flesh of one fish was found to have a high DDT concentration because of drainoff from agricultural land around the lakes. No one intended for the sea gulls on Long Island or the Coho salmon in Lake Michigan to accumulate DDT, but the unintended happened. Ironically enough, many pests tend to flourish under such circumstances because they are lower down the food chain and have a shorter lifetime; hence, they do not necessarily accumulate so much insecticide. The higher animals that formerly kept them in check meanwhile die off.

What do we do about DDT? How can we balance the increase in insect-free crop production and the decrease in insect-borne diseases like malaria against the contamination and death of higher animals that keep other pests in check? If we decide to forbid a course of action that offers immediate financial return to a farmer because the ultimate damage to society is greater, do we owe him compensation for our action? If so, who pays? Or do we convince him that no compensation is called for because he had no right to pollute the environment to his own gain in the first place? Such questions are not going to be solved by a panel of scientists, no matter how well informed. But neither can they be solved well by government policymakers, congressmen, or corporation advisory boards whose members are not literate in the field of chemistry. In the past, ignorance, if not bliss, was at least moderately harmless. Now, it can be disastrous. If the choice had to be made for the next generation between teaching chemists chemistry or teaching nonchemists chemistry, we could almost say that the latter course of action would be preferable.

From the preceding statements, chemistry may seem like only a scientific way of managing the planet. But man does not live by carbon dioxide-foamed wheat starch product alone. There is also the satisfaction of knowing what we are, and where we are, and where we came from. How did life evolve from nonliving chemical matter on this planet? How did this chemical matter itself arise? We cannot turn back the clock and watch the process, but we can set up what we believe to be primitive earth conditions and study the reactions that are likely to have taken place. We can see how the raw materials of living systems could have arisen naturally, and why more complex chemical assemblages would have been stable and long-lived. We can understand, in principle, how assemblages so complex that they must be called "living" would have developed. To a limited extent we can check our experimental paleochemistry with the evidence of mineral deposits laid down at various stages of the history of the earth. The apparently inhospitable conditions for life on the moon and possibly on Mars and Venus are disappointing, but they do not eliminate the fundamental question: "Given the proper conditions, is the evolution of life natural and virtually inevitable, or is its appearance on Earth a fortuitous accident?" We can design and carry out experiments which help to answer this question even if only one planet in our solar system were to prove to have the proper conditions.

Even if the moon does not reveal much about life, the chemistry of its rocks will allow us to reconstruct the history of the solar system. The first reports on lunar rock samples show a far higher concentration of high-melting-point metals than in any terrestrial ores. Does this mean that the moon solidified at high temperatures, at which much of the lighter material boiled away and was lost? Does the contrast between earth and moon mean that the moon was a wanderer captured by the earth rather than a daughter formed as the earth was? The answers to such queries will come, in part, from detailed chemical comparisons of the materials of earth and moon. Such efforts will not keep Lake Michigan from being polluted or make it possible for Earth to feed 10,000,000 more people, but they will provide a stretching of the human spirit that our species sorely needs.

Knowing where we came from and how we developed has an effect on how we think about ourselves. The revolution in thought that is sometimes symbolized by Copernicus and Galileo, which removed man from the center of the universe to one of several planets on a rather obscure star, shaped the patterns of thought of the citizens of Europe for generations. Man lives by ideas more than his pragmatist representatives in mid-twentieth century America like to admit. We are now slowly piecing together a new picture of man and his universe that is based on what we are learning in cosmology, astronomy, physics, geochemistry, molecular biochemistry, and behaviorial biology. This new picture of man will be as influential to future generations as the Renaissance picture of man was in its time. Chemistry has much to contribute to this picture of the nature of man and of his origins.

To the question "Why study chemistry?" there is a practical answer and an intangible answer. The practical answer is not the same as that of a generation ago; in part, today's answer is a need to make up for the blunders of the past. But just because the problem is more complicated, it is more interesting. We can begin to see wholes rather than parts, and the organization of a whole is almost always more interesting than the collection of parts. The intangible answer arises from the things that we can know from chemistry that we had no hope of knowing a generation ago: what life is, where it came from, how it operates, what our solar system is like, and how it arose. A man can be overwhelmed by a surfeit of knowledge, but understanding can be a source of strength. For the first time, in chemistry, we are on the verge of understanding.

Ernest Rutherford, in one of his less charitable moments, remarked that there are two kinds of science: physics and stamp collecting. Lavoisier and Dalton's atomic theory brought chemistry one step above stamp collecting. The quantum revolution of the 1920's and 30's set chemistry on the road to becoming a science, and the current studies of the chemistry of life promise to bring the field to the level where Rutherford's partisan figure of speech will have to be revised. Chemistry in the next generation will be fascinating and absorbing both as a participatory and a spectator sport.