INTRODUCTORY CHEMISTRY: A NEW VIEW

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Preface

Our everyday experiences have taught us many properties of common materials. We know, for example, that assorted materials respond differently to a hammer blow—a rock breaks, a metal fender dents, and a rubber ball bounces back to its original shape. The purpose of this book is to explain a few basic points about the workings of the universe that are responsible for properties we observe. A person acquainted with these basic points looks at the properties of various materials as repetitions of a familiar pattern rather than as unrelated information.

The first section of the book describes what scientists *do*. The discussion focuses on some familiar functions of the brain and sense organs that are the basis for scientific work. The human nervous system performs a number of processes, but scientists rely heavily on just a few of them. Although these few are familiar, it requires practice to recognize them in scientific discussions that usually concentrate on the topic in question and assume the reader already knows the basics of what scientists do. Hence a starting point for understanding scientific work is knowing what thinking processes scientists use to interpret the information about the universe that their senses bring in.

The next section of the book deals with what scientists have already *done*. They have discovered a few basic features of the universe that can account for every common happening. Most of the first half of the book is used to describe these features in language that is as free as possible from unnecessary mathematics and technical wording.

The rest of the book applies the basic patterns to familiar materials like rocks, metals, water, air, plastics, and petroleum. Mankind is beginning to have some problems with some of these materials, so an understanding of them and of the basic rules of the universe that they follow may help both in planning for the future and appreciating the present.

Contents

1. The World of Brain and Senses

Beginning the study of science is a little like watching a hockey game without knowing the rules. In both cases there seems to be no purpose to all the activity and one finds it difficult to pay attention. However, many people who have learned the rules for hockey or a similar sport can be absorbed in it for hours at a time. Perhaps if we go into the "rules" of science first, some of you will become interested in the chemistry of familiar things, like ice on which hockey is played.

There are a lot of old horror movies in which scientists are portrayed as weird individuals whose minds are in a wholly different world from that of most humans. However, the rules for scientific activity derive from the same basic mental processes that drive all human activity. Thus our look at chemistry will begin with a discussion of the human mind.

It is often useful to view the mind as analogous to an electric device that is built to do only certain things. We are thoroughly convinced that tape recorders cannot make toast, for example, and recognizing such convictions may help us to view the mind as designed for specific, limited operations. Help is necessary to reach this point of view because the mythology of our culture has held the mind capable of all things. Sigmund Freud made one of the first modern departures from this myth. He laid out what he believed to be the basic, built-in drives in every mind, and viewed mental illness as a loss of balance between these drives. He treated patients by trying to restore this balance through verbal tinkering analogous to turning knobs on a TV set to restore the picture.

Freud's ideas were the result of his seeing a common pattern in the childhood experiences described to him by many patients. He had no idea how the drives he noticed were produced by the electric equipment inside the skull. Indeed, thousands of present-day scientists have been using modern electric devices, electron microscopes, and computers on the brain for a generation without answering this question. This work has revealed quite a lot about the workings of the electrical components in the brain. What must still be determined are the sets of instructions, or "programs," that direct the components to respond as they do to information brought in by the senses. Many of the programs in the human brain are present at birth. Our cultural mythology has viewed a new human brain as a clean slate and has thus been opposed to the concept that much of our mental programming is part of the brain's design. However, the fact that babies breathe, eat, and eliminate wastes without requiring instruction is evidence that all human brains are built with some standard programs already in them.

The programs that control bodily processes are much less involved in scientific work than the ones that process information, or *think*. Since brain researchers are not yet able to get the instructions in programs by examining the electric circuits in which they are "written" in the brain, programs must be studied indirectly. Researchers, after watching the way people respond to selected information, look for patterns. Each particular pattern is presumed to be the result of a program being used. Research has shown that there are a multitude of programs that are much the same for all human beings and hence must be part of the brain's original equipment.

Studies of thinking programs have shown that this category has a large and diverse membership. For example, there is a group of psychological programs that work on information about oneself and interactions with other people. The work of Freud began the job of characterizing the programs. Despite several decades of research by thousands of people, we have achieved only fragmentary understanding of these programs. The problem is that the standard psychological programs in the brain at birth are geared subsequently to use information about each individual's past experiences in his dealing with new information. Since every person has different experiences, a variety of responses usually results when a number of people are given a particular piece of information. This lack of uniformity in people's responses to the same psychologically related information is a primary reason for resistance to the concept of the brain as a preprogrammed electric device. Electrical devices with which most people are familiar do not behave so indeterminately. For example, ten TVs set for channel 7 all bring in the same picture, whereas ten people asked "Does your mother like you?" are not likely to respond identically. Psychologists try to get around this complication by obtaining histories of their subjects and trying to filter out effects of experience on the responses. However, this method is not very reliable because the histories are never complete. (No psychologist has the time to find out every experience of all his subjects.)

Since our understanding of the brain's psychological programs is so limited, we cannot offer explanations for the motivations of past and present scientists. This is unfortunate because, we shall note later, there were psychological factors in the development of modern science. Fortunately, the programs that are used to *do* scientific work *have* been characterized, so we can discuss *what* scientists do even though we cannot show why other mental programs are urging them to do it.

The programs with which scientists work generate awareness of time and space from sensory data and construct relations between aspects of this awareness. A good name for them is *organizing programs*. We shall begin our examination of them with some programs that create relations.

The relating program that is the most important in science is the one that uses the mind to seek out and connect causes with effects. For example, if we see a man bowling, we should say that the rolling of the ball down the alley (an *effect*) is *caused* by the man's throwing it. One aspect of the cause–effect relation is sequence: effects always follow causes. However, two things that happen consecutively aren't always paired by the cause–effect program. For example, if it starts to rain just after someone yawns, we don't say the rain was caused by the yawn. Although we can give numerous examples of things that are and are not cause–effect pairs, we are not able to put into language how the cause–effect program in our mind makes the connection. The words used in any attempt are merely synonyms for cause or effect, which are in turn just *labels* for what the program does. To put this differently, we know the results of our cause–effect program, not the workings.

If the brain were not built to connect what we call cause with effect, human response to phenomena would be completely different. To illustrate this point, we need go no further than the first effect in a person's day, the noise of the alarm clock. If we made no connection between the noise and the clock causing it, we should never be able to shut it off, let alone make the connection with the time. Loss of the cause–effect program would, in addition to breaking up our whole fabric of response to events, destroy the curiosity that has been so useful to mankind. No other living thing has a cause–effect program as sophisticated as man's. For example, a rabbit trying to escape from a cage just bangs ineffectually against the sides instead of hunting for a cause of the confinement that it can alter.

Another organizing program besides cause–effect is making *comparisons*. There are certain kinds of relationships that people are built to recognize. For example, we can recognize a variety of equalities like equal times, identical colors, equal weights, or identical tastes. Notice that the quantities that are tested for equality are always detected by the same sense. We have no mental routines for cross comparisons between senses. We do have an organizing program called *counting*, which shows us a common factor in five gold bricks and five duck eggs. Like the cause–effect program, counting helps shape our view of the universe. Indeed, there are many professions whose main activity is counting (for example, bank tellers, band leaders, home plate umpires, census takers, accountants, and tax collectors).

Scientists often use counting along with comparison. It is possible to communicate about sensory information using these programs if the people involved establish a *standard*. For example, suppose sticks of equal length are passed out to each member of a group that agrees to call the length "one meter." The length of any object can then be measured in meters by *counting* the number of consecutive sticks that the *comparison* program rates equal to the length of the object. If one member of the group says "My bed is 2 meters long," the others understand because they too can count and know the length meant by "meter." Not all senses are programmed for numerical comparisons. Phrases like "twice as blue" or "half as sour" lack the distinct meaning of "twice as heavy."

Like cause–effect programs, our comparison and counting programs function separately from programs responsible for language. Hence we can compare and count sensory data but we can't tell even ourselves how we do it. These skills, along with our other mental programs, determine what we notice about the external universe and what we do with it. It's hard to get used to the idea that we can't explain them, but perhaps an example will help. Try to explain what "three" is without pointing to triplets of this and that. Realizing that the mind does things that are beyond conscious understanding is quite a jolt to anyone raised in our confident, "positive-thinking" culture. However, the "sanity" programs of the brain reject ideas that would cause intolerable stress, so nobody should suffer *too* much of a jolt.

There are different types of sensory information that scientists are concerned with. Each type is brought into existence by one or more of the sense organs and some programming in the brain that interprets the raw sensory impulses. Furthermore, only the organ–program coupling responsible for each type of information can generate it; *language* cannot. Language can only *label* sensory information. For example, the brain has a program to interpret visual input as what we call colors. However, this system malfunctions in some people. The label "blue" that we apply to a certain visual experience can never make a blue-yellow colorblind person understand what blue is.

The discontinuity between language and the senses limits what we can communicate about the physical world. We can only be aware of aspects of the physical world for which we have sensory detectors, and we can only communicate about sensory information by having an experience with someone who has the same senses and uses the same verbal labels. For example, we all learned about "hot" by having temperature sensors and touching a high-temperature object in the presence of someone who earlier had the same experience and was told the label.

Labels for the sensory information that scientists often use are given below along with the organs involved and the standards used. Each entry in the list illustrates how any meaning in a piece of sensory information always remains in the organ and brain program responsible for it.

1. *Length* is the name for the comparison by eye or touch of some object with ourselves. The organ-connected nature of length can be shown by supposing that you and a bat are considering the length of two special rooms. Bats have no eyes and perceive distance by measuring the time it takes sound to make a round trip between them and some object. One of the special rooms is fitted with walls that absorb all sound waves hitting them although they reflect light normally. Inside, the bat will perceive outdoors sensations because the sounds sent out never come back. However, the man's eyes will detect the walls. When a man is placed in a room containing properly adjusted mirrors, projectors, and other light-handling devices, he can be made to sense that he is outdoors. Since these devices have no special effect on sound, the bat under the same situation detects being in a room.

Which creature is "right" in these cases? Well, to themselves, the man and the bat are both right in each case. To both, the universe is what comes in through the senses. Here, of course, there are some deliberate alterations of the environment. In most cases there is no alternative "test" of what the senses perceive. Indeed, Einstein's theory of relativity has shown that length is not a fixed, unchangeable property of objects and that there is no way of knowing whether you and your surroundings change in length.

The scientist's standard for length is called the meter and is equal to 1.09 U.S. yards. The *metric* system is built around multiples of 10 with labels that are derived from Greek or Latin. For example, a *centi*meter (0.39 inch) is $\frac{1}{100}$ meter and a *kilo*meter (0.62 mile) is 1000 meters. Length in three dimensions is called *volume*. There is no U.S. equivalent for the volume of a cube whose sides measure 1 centimeter, but 1000 cubic centimeters (called a *liter*) is 1.06 U.S. quarts.

2. *Force* is the name for the signals from several sources: touch sensors, gauges of muscle strain, and the inner ears. Whatever force is, the earth exerts a lot of it. For example, right now your touch sensors are busy registering that the part of you nearest the ground wants to get nearer still. Try to move something away from the earth and your muscles will feel the earth try to pull it back again.

To perceive man's inability to induce the force sensation with language, let us suppose you are asked to get across the idea of force to a child that was born paralyzed and numb. The child's touch sensors and muscles cannot deliver any force sensations to his brain, so the learning by imitation method of teaching will not work. He cannot lift a heavy object, and when you push on him, he does not feel it. When you try words, the explanations all contain synonyms of "push" and "pull," which are just labels for what a person with working force sensors feels.

The standard for force is seldom used in everyday life. We do have experience, however, with "weight," which describes how hard the earth pulls on various quantities of matter. Units of *weight* are thus seen to be indirect measures of force.

3. *Time* is a concept involving both sequence and intervals. The organ whose output is labeled by "sequence" is the memory department of the brain. To put a series of events in order, one must remember the ones that have already happened. Many simple species lack memory equipment. For example, some aquatic microorganisms will move towards a light, but the instant the light is extinguished, their movement becomes completely random. These creatures have only a present, a situation impossible for beings with memory to comprehend.

In addition to memory, human awareness of time involves a part of the brain that ticks off *intervals* of time. The comparing and counting programs are built to handle signals from this device, so it is possible to establish a standard and measure time. The standard unit of time is the second. Its origin no doubt derives from its being about the duration of one heartbeat.

4. Our *temperature* sensors supply information about the universe that laymen discuss less often than force, length, and time. Although there are some absolute aspects to temperature, human temperature sensors are relative; that is, the same tub of water will feel colder to a man just out of a steam room than to someone coming from a deep freeze. As with the other sense perceptions, there is not much backup on temperature sensors. They *are* what make us recognize a difference between a pan just out of the oven and one just out of the refrigerator. We will defer comment on the measurement of temperature until much later.

The causes and effects that scientists have noted in studying the physical universe are almost always either length, force, time, temperature, or some combination of these quantities. People use other sensory perceptions such as taste, smell, hearing, and pain to determine their personal situation in the universe, but these perceptions are seldom observed to be causes or effects in the universe outside of human beings.

Creatures that lack organs like ours do not perceive the universe as we do. A contemplative person might wonder if there are things in the universe that *we* cannot detect. Scientists have observed effects whose causes people cannot sense. As we will soon see, electromagnetic phenomena are among these. For example, our senses cannot tell if a piece of metal is magnetic, but if we bring up another magnet, our senses can detect the force of repulsion or attraction. If something causes no detectable effects around us, we cannot know of its existence.

Problems

1. What three subprograms of "organizing" do scientists use? For each one, briefly describe what the program can and cannot do.
2. Think of some pairs of happenings you connect as cause and effect. Try to explain how you made the connection, but do not use any synonyms for *cause* or *effect*. The text claims such explanations are impossible. Do you believe it?
3. How do cause–effect, counting, and comparison shape our universe?
4. To what low-level role has the text relegated *language*?
5. What is a *standard,* and what deficiency in language does it circumvent to allow communication about sense data?
6. Why, do you suppose, does a dog or cat that has been raised among talking human beings never start talking himself?
7. Explain why it would be more precise to say "our" universe rather than "the" universe.
8. What are the organizing categories for sense information that scientists use? Would a creature lacking sense organs and a brain like man's comprehend any of them?

2. What Scientists Do

2.1 Inductive Reasoning

The brain is programmed to organize information by labeling, measuring, and seeking causes for observed effects. Scientists apply these programs to sense input from the physical world. From the labels and standards that express the information, they can undertake the cause–effect studies.

Scientists have no particular monopoly on cause and effect; all human beings need to put "becauses" with "whys." However, the 17th century men who were the first modern scientists varied on the basic process. Our world is full of things that change position with time (or *move*), and these men studied motion. They did experiments in which objects were moved by exerting a force on them, so in these cases, they could say, pushing on the objects was the cause of their moving. But unlike their more cautious predecessors, they "jumped to conclusions" from their experiences and said that every *future* instance of pushing on an object would result in motion.

Human beings have equipment that detects the past and present but not the future. Throughout recorded history curious men have sought a method for detecting the future. This search has involved such diverse activities as consulting the heavenly bodies, in astrology, and examining chicken entrails, in soothsaying. In the area of human events, no reliable way to detect the future has yet been developed. However, in the physical world, jumping to conclusions from past experience has worked quite well. For example, in the last 300 years at least, every case of pushing on an unrestrained object has caused motion. This technique of constructing a general principle from a few cases has the formal name of *inductive reasoning*. It has allowed scientists to simulate "sensing" the future.

Of course, there is no way to *prove* an induced principle by demonstration to the senses because, by definition, the future never arrives. Tomorrow, pushing on an object may not cause it to move. Scholars from the time of the ancient Greeks have known about inductive reasoning but the early scholars hesitated to use it on the physical world because of the inherent uncertainty. Hence, the use of induction by the first modern scientists represented a new psychological situation rather than invention of a new technique. These men were more interested in expediency than in the certainty the ancient Greeks sought.

The centuries of success in applying inductive reasoning to the physical world show that the universe brought in by our senses has regularity. If the rules that seem to apply to the physical world are changing, they are changing so slowly that men have not yet noticed.

The not-so-shaky conclusions to which scientists jump have valuable uses: they permit predictions, and they provide organizing principles that can be used to classify many seemingly different events under one heading. For example, if we could have shown one of these early students of force and motion a rocket (although rockets did not exist in his time), he would have used his "law" to predict that the rocket would take off. (Indeed, the men who designed the rocket used the same law.) The force–motion connection shows up in the wind-blown leaves, engine-driven cars, gravity-propelled water, and so on, and thus allows us to say that all motions we observe have something in common: force causes them.

The early scientists, besides noting the qualitative connection of force and motion, also made quantitative studies of how much force produced a particular amount of motion. They used various mathematical techniques, some of which they had to invent, to hunt for simple organizing principles reflected by the data.

Galileo demonstrated such work in a classic example. He dropped objects of various weights off the Tower of Pisa and determined the time required for the force of gravity to move them to the ground. Figure 2–1 shows some simulated experimental results expressed in modern units of measure. Only a few weights were actually tried, but an inductive reasoner looking at the figure would conclude that an object of any weight would take four seconds to fall. The dotted line in Figure 2–1 indicates this trend. The general principle in the specific cases is evident here, but many of the results of force–motion studies required complex mathematical treatment to locate an underlying principle.

2.2 Newton's Law

Galileo was only one of many people who experimented on force and motion. Some workers used the force of gravity; others tried springs, gunpowder, and so on. A few, like Kepler, sat in observatories and analyzed the motions of the planets.

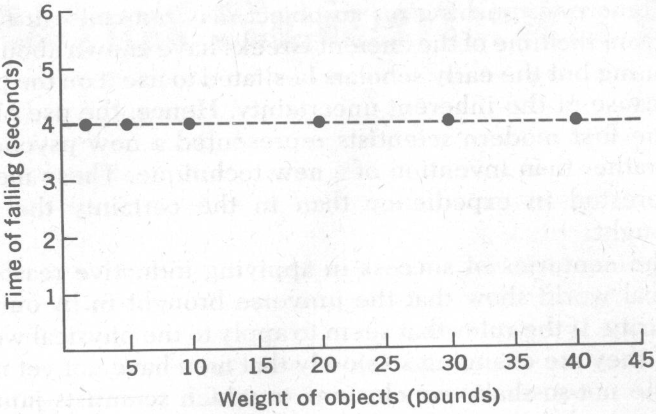

FIGURE 2–1

A few times in the history of modern science someone has seen a simplifying principle that draws together a large number of seemingly separate findings. Isaac Newton did this with all the work on force and motion that preceded him. We express his law today as

$$F = m \cdot a \tag{2.1}$$

The symbol *F* represents force; *a* is acceleration, which means change in speed or direction with time. Expressed in words, the *F* to *a* relation in Newton's law says that pushing on something causes its motion to change. Pushing a stationary object will initiate motion; pushing to resist motion of an object already under way will stop it. We all have experiences that illustrate Newton's law. For example, consider a bowling ball and a long, long alley. Until someone applies a force to the ball, it remains stationary. After a forceful throw changes the ball's speed from zero to a few feet per second, the ball will keep going at that speed and in the same direction, unless affected by forces from spin or friction with the alley. Hitting the back wall of the alley exerts a counterforce on the ball and changes its speed from a few feet per second back to zero. The "*m*" in Newton's law stands for *mass*, which is a property of matter discovered by the early scientists. Apparently matter resists attempts to alter its motion. Newton's law says the the more the matter, or mass, that is contained in an object, the greater the force required to overcome this resistance and produce a specified acceleration. For example, the feeble force from a man's arm can accelerate the mass of a baseball from zero to 60 miles per hour. However, the large force of an auto engine is needed to produce the same acceleration on the large mass of a car. If a constant force is being used on different amounts of matter, the smallest mass will be accelerated the most, according to Newton's law. One can obtain a practical feel for this relation by kicking a soccer ball and then a massive boulder with the same force and noting the resulting accelerations.

The *standard* used for mass is the amount of matter in one cubic centimeter of water, which is called one *gram*. One kilogram (1000 g) has the same mass as an object weighing 2.2 pounds. Strictly speaking, weight is the *force* that the earth's gravity exerts on some mass. Another piece of work by Newton showed that the acceleration of gravity is the same on any mass; so on the earth's surface, weight and mass both tell about a piece of matter's response to force. In outer space, where there is no gravity, objects have no weight, but they have the same resistance to acceleration or mass that they do on earth.

Some perceptive reader may correctly say, "OK, Newton's law seems to account for the force–motion behavior we observe, but it doesn't say *why* the universe works that way." This situation arises because we do not have conscious understanding of our cause–effect program. The program "rings a bell" for our conscious when it "computes" two things in the correct relation but this only tells us *that* two events are connected, not *why* they are. Indeed, the word "why" is just a request to run the program and find the cause of some effect. (Note that the response to "why" is "be*cause*"!) We are therefore not capable of answering "whys" about things outside our senses and conscious awareness. How the cause–effect program works is one of these outside, unknowable things. Just as a bat can never know color, people can never know "why" any cause is connected to its effect. We can only know that it *is*. Of course, people continue to ask why persistently, and the idea that it is sometimes futile is hard to accept. Indeed, people often make up causes for effects if no cause is detected by their senses. For example, there is usually no detectable cause for bad luck like being hit by a drunken driver, but throughout history people have made up causes like "evil spirits." The popular scientific mystique says that scientists have gone beyond the superstitious thinking that invents an imaginary cause when none is apparent. However, as we shall soon discover, most of the scientific view of matter is built around made-up causes that can't be proved by the senses any more than evil spirits can. This point reemphasizes the idea that scientists are applying to the physical world the kinds of mental processes that all human beings use.

2.3 Energy

Scientists have found it useful to concoct a number of mixes of force, length, and time for convenience in dealing with the physical events we are able to sense. We are familiar with some of these;