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Chapter 1

What Is Chemistry, and Why Do I Need to Know Some?

If you're taking a course in chemistry, you may want to skip this chapter and go right to the area you're having trouble with. You already know what chemistry is — it's a course you have to pass. But if you bought this book to help you decide whether to take a course in chemistry or to have fun discovering something new, I encourage you to read this chapter. I set the stage for the rest of the book here by showing you what chemistry is, what chemists do, and why you should be interested in chemistry.

I really enjoy chemistry. It's far more than a simple collection of facts and a body of knowledge. I was a physics major when I entered college, but I was hooked when I took my first chemistry course. It seemed so interesting, so logical. I think it's fascinating to watch chemical changes take place, to figure out unknowns, to use instruments, to extend my senses, and to make predictions and figure out why they were right or wrong. The whole field of chemistry starts here — with the basics — so consider this chapter your jumping-off point. Welcome to the interesting world of chemistry.

Understanding What Chemistry Is

This whole branch of science is all about *matter,* which is anything that has mass and occupies space. *Chemistry* is the study of the composition and properties of matter and the changes it undergoes, including energy changes.

Science used to be divided into very clearly defined areas: If it was alive, it was biology. If it was a rock, it was geology. If it smelled, it was chemistry. If it didn't work, it was physics. In today's world, however, those clear divisions are no longer present. You can find biochemists, chemical physicists, geochemists, and so on. But chemistry still focuses on matter and energy and their changes.

A lot of chemistry comes into play with that last part — the changes matter undergoes. Matter is made up of either pure substances or mixtures of pure substances. The change from one substance into another is what chemists call a *chemical change,* or *chemical reaction,* and it's a big deal because when it occurs, a brand-new substance is created (see Chapter 3 for the nitty-gritty details).

So what are compounds and elements? Just more of the anatomy of matter. Matter is pure substances or mixtures of pure substances, and substances themselves are made up of either elements or compounds. (Chapter 3 dissects the anatomy of matter. And, as with all matters of dissection, it's best to be prepared — with a nose plug and an empty stomach.)

Distinguishing between Science and Technology

Science is far more than a collection of facts, figures, graphs, and tables. Science is a method for examining the physical universe. It's a way of asking and answering questions. However, in order for it to be called science, it must be testable. Being testable is what makes science different from faith.

For example, you may believe in UFOs, but can you test for their existence? How about matters of love? Does she love me? How much does she love me? Can I design a test to test and quantify that love? I think not. I have to accept that love on faith. It's not based in science, which is okay. Humankind has struggled with many great questions that science can't answer. Science is a tool that is useful in examining certain questions, but not all. You wouldn't use a front-end loader to eat a piece of pie, nor would you dig a ditch with a fork. Those are inappropriate tools for the task, just as science is an inappropriate tool for areas of faith.

Science is best described by the attitudes of scientists themselves: They're skeptical. They simply won't take another person's word for a phenomenon — it must be testable. And they hold onto the results of their experiments tentatively, waiting for another scientist to disprove them. Scientists wonder, they question, they strive to find out *why,* and they experiment — they have exactly the same attitudes that most small children have before they grow up. Maybe this is a good definition of scientists — they are adults who've never lost that wonder of nature and the desire to know.

Technology, the use of knowledge toward a very specific goal, actually developed before science. Ancient peoples cooked food, smelted ores, made beer and wine by fermentation, and made drugs and dyes from plant material. Technology initially existed without much science. There were few theories and few true experiments. Reasoning was left to the philosophers. Eventually alchemy arose and gave chemistry its experimental basis. Alchemists searched for ways to turn other metals into gold and, in doing so, discovered many new chemical substances and processes, such as distillation. However, it wasn't until the 17th century that experimentation replaced serendipity (see the next section for a discussion of serendipity) and true science began.

Deciphering the Scientific Method

The *scientific method* is normally described as the way scientists go about examining the physical world around them. In fact, no one uses just one scientific method every time, but the one I cover here describes most of the critical steps scientists go through sooner or later. Figure 1-1 shows the different steps in the scientific method.

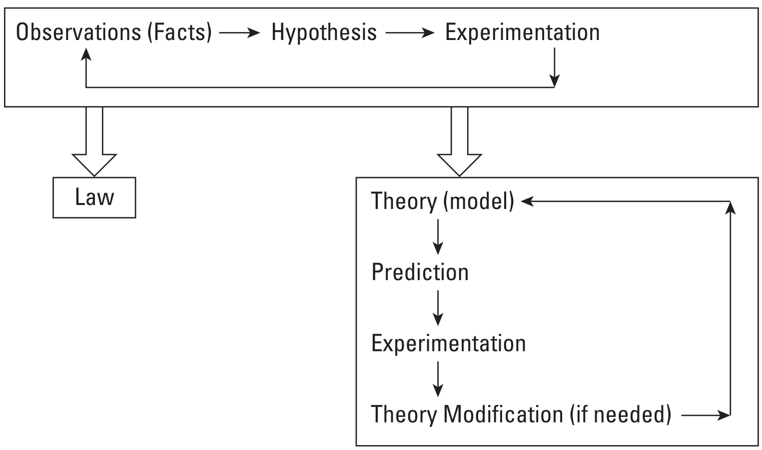

FIGURE 1-1: The scientific method.

The following sections examine more in-depth what the scientific method is and how you can use it in all your studies, not just chemistry.

How the scientific method works

The way scientists are supposed to do their jobs is through the scientific method: a circular process that goes from observations to hypotheses to experiments and back to observations. These steps may lead in some cases to the creation of laws or theories.

REMEMBER

To begin the scientific method, scientists make *observations* and note facts regarding something in the physical universe. The observations may raise a question or problem that the researcher wants to solve. They come up with a *hypothesis*, a tentative explanation that's consistent with the observations (in other words, an educated guess). The researcher then designs an *experiment* to test the hypothesis. This experiment generates observations or facts that can then be used to generate another hypothesis or modify the current one. Then more experiments are designed, and the loop continues.

In good science, this loop of observations, hypothesis, and experimentation never ends. As scientists become more sophisticated in their scientific skills, think of better ways of examining nature, and build better and better instruments, their hypotheses are tested over and over. Conclusions that may appear to be scientifically sound today may be modified or even refuted tomorrow.

Besides continuing the loop, good experiments done with the scientific method may lead the researcher to propose a law or theory. A *law* is simply a generalization of what happens in the scientific system being studied. For example, the law of conservation of matter stated that matter is neither created nor destroyed. And like the laws that have been created for the judicial system, scientific laws sometimes have to be modified based on new facts. With the dawn of the nuclear age, scientists realized that in nuclear reactions a small amount of matter disappears and is converted to energy. So the law of conservation of matter was changed to read: In ordinary chemical reactions, matter is neither created nor destroyed.

A theory or model may also be proposed. A *theory* or *model* attempts to explain *why* something happens. It's similar to a hypothesis except that it has much more evidence to support it. What separates a theory from an opinion is that it has numerous experiments, many observations, and lots of data — in a nutshell, facts — supporting it.

The power of the theory or model is prediction. If the scientist can use the model to gain a good understanding of the system, then they can make predictions based on the model and then check them out with more experimentation. The observations from this experimentation can be used to refine or modify the theory or model, thus establishing another loop in the process. When does it end? Never. Again, as humankind develops more advanced instrumentation and ways of examining nature, scientists may find it necessary to modify their theories or models.

Many scientific discoveries are made through the scientific method. However, many discoveries are made by another process, called serendipity. *Serendipity* is an accidental discovery. The discoveries of penicillin, sticky notes, Velcro, radioactivity, Viagra, and so on were made by accident. But recognizing an accidental discovery takes a well-trained, disciplined, scientific mind. See Chapter 21 for a list of what I consider to be ten important serendipitous discoveries in chemistry.

How you can use the scientific method

Most people use the scientific method in their everyday lives without even thinking about it. You just think of it as tackling a problem logically. For example, suppose you buy that new HD TV and home theater system you've been wanting. After unpacking and hooking everything up, you notice that you have no sound coming out of the left speakers when the TV is playing. You've identified a problem to investigate. Now you need to apply the scientific method to solve the problem. Here are some general steps to use:

1. **Develop a hypothesis about what you're studying.**

   REMEMBER

   This hypothesis is an educated guess you make about what you think the end results will be. A hypothesis gives you an idea of what to expect, although after you conduct your experiments, you may determine the hypothesis is invalid.

   For example, in the case of the dead left speakers, you may think that the problem lies with the TV, the receiver, or the cables connecting the two because everything else is working correctly. You form the hypothesis that something is wrong with the TV cables, that perhaps the left wire is broken or its connection is bad. You decide to experiment.

2. **Conduct your experiment.**

   Carefully design this experiment, with as many variables as possible being controlled. *Variables* are factors that can affect the outcome of the experiment. In chemistry, variables may be temperature, pressure, volume, and so on. (Controlling all the variables is very difficult when human beings are involved, which is why social-science experiments are so difficult.) In this example, the connections at both the TV and the receiver are variables, as is the cable between the connections. You would only want to change one thing at a time. The simplest thing to do is to switch how the cable is connected at the TV. Just switch the right cable lead with the left one and vice versa. Suppose the left speakers are playing but the right set is dead. What does that tell you?

3. **Use the data and information from the experiment to generate a new hypothesis or modify the old one.**

   Because the opposite speakers began malfunctioning when the TV cable connections were swapped, either the TV or the cable must be faulty, not the receiver. So you conduct another experiment, using a new set of cables. Thank goodness, everything is now playing just fine.

IDENTIFYING CHEMISTRY IN THE HOME

Chemistry is an important fact of everyday life. You can walk around your home to see all the chemistry-related things that are important to you. Check out chemistry in these rooms in your home:

- **Laundry room:** See that bottle of laundry detergent? Both the bottle and the detergent itself were made by chemists. You like those nice clean clothes, right? Without chemistry, you couldn't dress nearly as nice. Detergents contain a lot of things, including enzymes, brighteners, fillers, and so on, all of which chemists designed to make your clothes look good. Grab a bottle of bleach. Yep, made by chemists. Whether it be your clothes or your hair or wood pulp, chemists can get the color out of almost anything.
- **Closet:** If you wear clothes of something other than wool or cotton, you can thank a chemist and the chemical industry that discovered how to make those fibers.
- **Bathroom:** See that bar of soap? It was perfected by a chemist; otherwise, you would have to put up with grandma's harsh lye soap.

  How about that toothpaste? There are a lot of ingredients in that simple product: colors, flavors, abrasives, thickeners, and fluoride, all designed by chemists. And I certainly hope that you use a deodorant. Every wonder what it contains? You can bet the formulation was developed by chemists.

  What do you put on your skin? Probably lotions, powders, makeup, or cologne that was developed by chemists. And your hair — you wash it, curl it, straighten it, and color it, all with chemicals.

  I know, it's enough to give you a headache. That aspirin you are getting ready to take is made by chemists, as well as the acetometaphin, ibuprofen, and so on. Chemicals are everywhere. Pull your hair out — and grow it back with a drug.

Chemists have given you the things you enjoy. Sometimes, problems arise in the process. Chemists have been, and continue to be, called upon to solve those problems.

You may argue that the procedure you used was just common sense, but it really was the scientific method. In fact, I really do think of the scientific method as just good common sense.

Looking at the Branches of Chemistry

The general field of chemistry is so huge that it was originally subdivided into a number of different areas of specialization. But the different areas of chemistry now have a tremendous amount of overlap, just as there is among the various sciences. Here are the traditional fields of chemistry:

- **Analytical chemistry:** This branch is highly involved in the analysis of substances. Chemists from this field of chemistry may be trying to find out what substances are in a mixture (*qualitative analysis*) or how much of a particular substance is present (*quantitative analysis*) in something. Analytical chemists typically work in industry in product development or quality control. If a chemical manufacturing process goes wrong and is costing that industry hundreds of thousands of dollars an hour, that quality control chemist is under a lot of pressure to fix it and fix it fast. A lot of instrumentation is used in analytical chemistry. Chapters 7 through 9 cover a lot of the concepts that analytical chemists use.
- **Biochemistry:** This branch specializes in living organisms and systems. Biochemists study the chemical reactions that occur at the *molecular level* of an organism — the level where items are so small that people can't directly see them. Biochemists study processes such as digestion, metabolism, reproduction, respiration, and so on. Sometimes, distinguishing between a biochemist and a molecular biologist is difficult because they both study living systems at a microscopic level. However, a biochemist really concentrates more on the reactions that are occurring. For a good taste of biochemistry, see my book *Biochemistry For Dummies.*
- **Biotechnology:** This relatively new area of science is commonly placed with chemistry. It's the application of biochemistry and biology when creating or modifying genetic material or organisms for specific purposes. Biotechnology is used in such areas as cloning and the creation of disease-resistant crops, and it has the potential for eliminating genetic diseases in the future. I also discuss this field in *Biochemistry For Dummies* (Wiley).
- **Inorganic chemistry:** This branch is involved in the study of inorganic compounds such as salts. It includes the study of the structure and properties of these compounds. It also commonly involves the study of the individual

elements of the compounds. Inorganic chemists would probably say that it is the study of everything except carbon, which they leave to the organic chemists.

- **Organic chemistry:** This is the study of carbon and its compounds. It's probably the most organized of all the areas of chemistry — with good reason. There are millions of organic compounds, with thousands more discovered or created each year. Industries such as the polymer industry, the petrochemical industry, and the pharmaceutical industry depend on organic chemists.
- **Physical chemistry:** This branch figures out how and why a chemical system behaves as it does. Physical chemists study the physical properties and behavior of matter and try to develop models and theories that describe this behavior. Chapters 10 and 15 involve topics that physical chemists love.

Chemists, no matter what the type, all tend to examine the world around them in two ways — a macroscopic view and a microscopic view. The following sections take a look at these two viewpoints.

Macroscopic versus microscopic viewpoints

Most chemists that I know operate quite comfortably in two worlds. One is the *macroscopic* world that you and I see, feel, and touch. It's the world of stained lab coats — of weighing out things like sodium chloride to create things like chlorine gas. The macroscopic realm is the world of experiments, or what some nonscientists call the "real world."

But chemists also operate quite comfortably in the *microscopic* world that you and I can't directly see, feel, or touch. Here, chemists work with theories and models. They may measure the volume and pressure of a gas in the macroscopic world, but they have to mentally translate the measurements into how close the gas particles are in the microscopic world.

Scientists often become so accustomed to slipping back and forth between these two worlds that they do so without even realizing it. An occurrence or observation in the macroscopic world generates an idea related to the microscopic world, and vice versa. You may find this flow of ideas disconcerting at first. But as you study chemistry, you'll soon adjust so that it becomes second nature.

Pure versus applied chemistry

In *pure chemistry*, chemists are free to carry out whatever research interests them — or whatever research they can get funded. They don't necessarily expect to find a practical application for their research at this point. The researchers simply want to know for the sake of knowledge. This type of research (often called *basic research*) is most commonly conducted at colleges and universities. Chemists use undergraduate and graduate students to help conduct the research. The work becomes part of the professional training of the student. Researchers publish their results in professional journals for other chemists to examine and attempt to refute. Funding is almost always a problem, because the experimentation, chemicals, and equipment are quite expensive.

In *applied chemistry,* chemists normally work for private corporations. Their research is directed toward a very specific short-term goal set by the company — product improvement such as the development of a disease-resistant strain of corn. Normally, more money is available for equipment and instrumentation with applied chemistry, but the chemists also have the pressure of meeting the company's goals.

These two types of chemistry, pure and applied, share the same basic differences as science and technology. In *science,* the goal is simply the basic acquisition of knowledge without any need for apparent practical application. Science is simply knowledge for knowledge's sake. *Technology* is the application of science toward a very specific goal.

Our society has a place for both science *and* technology — likewise for the two types of chemistry. The pure chemist generates data and information that is then used by the applied chemist. Both types of chemists have their own sets of strengths, problems, and pressures. In fact, because of dwindling federal research dollars, many universities are becoming much more involved in gaining patents, and they're being paid for technology transfers into the private sector.

Eyeing What You'll Do in Your Chemistry Class

I bet that somewhere along the way, you wondered what you would be doing in your chemistry class. Perhaps that was the motivation that led you to buy this book. The activities that you will do in class, especially the laboratory portion, are the very activities that professional chemists earn a living doing. You can group the activities of chemists (and chemistry students) into these major categories:

» **Chemists (and chemistry students) analyze substances.** They determine what is in a substance, how much of something is in a substance, or both. They analyze solids, liquids, and gases. They may try to find the active compound in a substance found in nature, or they may analyze water to see how much lead is present. (See Chapters 7 and 9.)

- **Chemists (and chemistry students) create, or *synthesize,* new substances.** They may try to make the synthetic version of a substance found in nature, or they may create an entirely new and unique compound. They may try to find a way to synthesize insulin. They may create a new plastic, pill, or paint. Or they may try to find a new, more efficient process to use for the production of an established product. (See Chapters 7 and 8.)
- **Chemists (and chemistry students) create models and test the predictive power of theories.** This area of chemistry is referred to as *theoretical chemistry.* Chemists who work in this branch of chemistry use computers to model chemical systems. Theirs is the world of mathematics and computers. Some of these chemists don't even own a lab coat. (See Chapters 6 and 15.)
- **Chemists (and chemistry students) measure the physical properties of substances.** They may take new compounds and measure their melting points and boiling points. They may measure the strength of a new polymer strand or determine the octane rating of a new gasoline. (See Chapter 10.)