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2nd Edition

Chemistry

for **dummies**®

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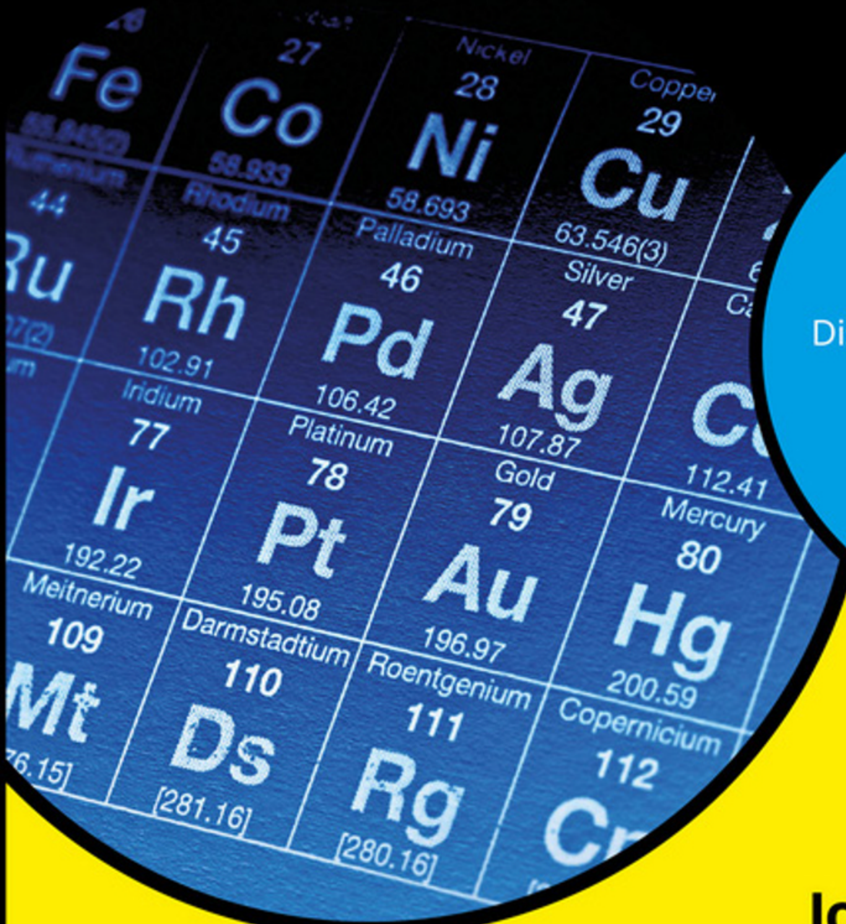

Grasp basic chemistry principles

Discover chemical reactions and bonds

Make sense of matter and energy

John T. Moore, EdD

Chemistry for dummies

A Wiley Brand

2nd edition

by John T. Moore, EdD

Professor of Chemistry, Stephen F. Austin State University

for dummies

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Contents at a Glance

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Introduction

You've passed the first hurdle in understanding a little about chemistry: You've picked up *Chemistry For Dummies,* 2nd Edition. I imagine that a large number of people looked at the title, saw the word *chemistry,* and bypassed it like it was covered in germs.

I don't know how many times I've been on vacation, struck up a conversation with someone, and been asked the dreaded question: "What do you do?"

"I'm a teacher," I reply.

"Really? And what do you teach?"

I steel myself, grit my teeth, and say in my most pleasant voice, "Chemistry."

I see The Expression, followed by, "Oh, I never took chemistry. It was too hard." Or "You must be smart to teach chemistry." Or "Goodbye!" If I were still in the dating scene, "Hi, I teach chemistry" would not be a good pick-up line!

I think a lot of people feel this way because they think that chemistry is too abstract, too mathematical, too removed from their real lives. But in one way or another, all of us do chemistry.

Remember making that baking soda and vinegar volcano as a child? That's chemistry. Do you cook or clean or use fingernail polish remover? All that is chemistry. I never had a chemistry set as a child, but I always loved science. My high school chemistry teacher was a great biology teacher but really didn't know much chemistry. But when I took my first chemistry course in college, the labs hooked me. I enjoyed seeing the colors of the solids coming out of solutions. I enjoyed *synthesis,* making new compounds. The idea of making something nobody else had ever made before fascinated me. I wanted to work for a chemical company, doing research, but then I discovered my second love: teaching.

Chemistry is sometimes called the central science (mostly by chemists), because in order to have a good understanding of biology or geology or even physics, you must have a good understanding of chemistry. Ours is a chemical world, and I hope that you enjoy discovering the chemical nature of it — and that afterward, you won't find the word *chemistry* so frightening.

About This Book

My goal with this book is not to make you into a chemistry major. My goal is simply to give you a basic understanding of some chemical topics that commonly appear in high school or college introductory chemistry courses. If you're taking a course, use this book as a reference in conjunction with your notes and textbook.

Simply watching people play tennis, no matter how intently you watch them, will not make you a tennis star. You need to practice. And the same is true with chemistry. It's *not* a spectator sport. If you're taking a chemistry course, then you need to practice and work on problems. I show you how to work certain types of problems — gas laws, for example — but use your textbook for practice problems. It's work, yes, but it really can be fun.

As I updated this second edition of *Chemistry For Dummies,* I reflected on what to include. I've enjoyed getting e-mails from people all over the world asking questions about the first edition or thanking me. However, looking at the overall feedback, I felt that I hadn't included quite enough about calculations and some other topics that students taking a college or high school–level class really needed. So in this second edition I beefed up the calculations and included some extra topics normally found in the first year of high school chemistry or the first semester of general chemistry in college. Overall, this edition will be more useful to those of you taking the chemistry course. For those of you who want some help with second-semester topics, hang in there and maybe, just maybe, you'll soon see *Chemistry II For Dummies* in your local bookstore.

Foolish Assumptions

I really don't know why you bought this book (or will buy it — in fact, if you're still in the bookstore and *haven't* bought it yet, buy two and give one as a gift), but I assume that you're taking (or retaking) a chemistry course or preparing to take a chemistry course. I also assume that you feel relatively comfortable with arithmetic and know enough algebra to solve for a single unknown in an equation. And I assume that you have a scientific calculator capable of doing exponents and logarithms.

And if you're buying this book just for the thrill of finding out about something different — with no plan of ever taking a chemistry course — I applaud you and hope that you enjoy this adventure. Feel free to skip those topics that don't hold your interest; for you, there will be no tests, only the thrill of increasing your knowledge about something new.

What Not to Read

I know you're a busy person and want to get just what you need from this book. Although I want you to read every single word I've written, I understand you may be on a time crunch. I keep the material to the bare bones, but I include a few sidebars. They're interesting reading (again, at least to me) but not really necessary for understanding the topic at hand, so feel free to skip them. This is *your* book; use it any way you want.

I mark some paragraphs with Technical Stuff icons. What I tell you in these paragraphs is more than you need to know, strictly speaking, but it may give you helpful or interesting detail about the topic at hand. If you want just the facts, you can skip these paragraphs.

How This Book Is Organized

I present this book's content in a logical progression of topics. But this doesn't mean you have to start at the beginning and read to the end of the book. Each chapter is self-contained, so feel free to skip around. Sometimes, though, you'll get a better understanding if you do a quick scan of a background section as you're reading. To help you find appropriate background sections, I've placed "see Chapter X for more information" cross-references here and there throughout the book.

Because I'm a firm believer in concrete examples, I also include lots of illustrations and figures with the text. They really help in the understanding of chemistry topics. And to help you with the math, I break up problems into steps so that you can easily follow exactly what I'm doing.

I've organized the topics in a logical progression — basically the same way I organize my courses for science and non-science majors. Following is an overview of each part of the book.

Part 1: The Basic Concepts of Chemistry

In this part, I introduce you to the really basic concepts of chemistry. I define chemistry and show you where it fits among the other sciences (in the center, naturally). I show you the chemical world around you and explain why chemistry should be important to you. I also have a chapter (Chapter 2) devoted to chemical calculations. I show you how to use the factor label method of calculations, along with an introduction to the SI (metric) system. I also show you the three states of matter and talk about going from one state to another — and the energy changes that occur.

Besides covering the macroscopic world of things like melting ice, I cover the microscopic world of atoms. I explain the particles that make up the atom — protons, neutrons, and electrons — and show you where they're located in the atom.

I discuss how to use the periodic table, an indispensable tool for chemists. And I introduce you to the atomic nucleus, including the different subatomic particles. Finally, I introduce you to the wonderful world of gases. In fact, in the gas chapter, you can see so many gas laws (Boyle's law, Charles's law, Gay-Lussac's law, the combined gas law, the ideal gas law, Avogadro's law, and more) that you may feel like a lawyer when you're done. The material in these chapters gets you ready for additional topics in chemistry.

Part 2: A Cornucopia of Chemical Concepts

In this part, you get into some really good stuff: chemical reactions. I give some examples of the different kinds of chemical reactions you may encounter and show you how to balance them. (You really didn't think I could resist that, did you?) I also introduce the mole concept. Odd name, yes, but the mole is central to your understanding of chemical calculations. It enables you to figure the amount of reactants needed in chemical reactions and the amount of product formed. I also talk about solutions and how to calculate their concentrations. And I explain why I leave the antifreeze in my radiator during the summer and why I add rock salt to the ice when I'm making ice cream.

This part gets into thermochemistry. Energy changes take place during chemical reactions. Some reactions give off energy (mostly in the form of heat), and some absorb energy in the form of heat. I show you how to figure how much heat is released. It may be enough to make you break out in a sweat. Finally, I tell you about acids and bases, things sour and things bitter. I discuss how to calculate their concentration and the pH of a solution.

Part 3: Blessed Be the Bonds That Tie

I start off in this part talking about quantum theory, through which an electron can be represented by the properties of both particles and waves. In the first chapter, I throw certainties out the window and introduce you to probabilities. Then I explain bonding. I show you how table salt is made in Chapter 13, which covers ionic bonding, and I show you the covalent bonding of water in Chapter 14. I explain how to name some ionic compounds and how to draw Lewis structural formulas of some covalent ones. I even show you what some of the molecules look like. (Rest assured that I define all these techno-buzzwords on the spot, too.)

I also talk about periodic trends of the elements and intermolecular forces, those extremely important forces that give water its most unusual properties.

Part 4: Environmental Chemistry: Benefits and Problems

In this part, I discuss some environmental issues, specifically air and water pollution. I demonstrate what causes those pollutants and what chemistry can do to correct those problems. These issues, which are so often in the news, are among the most important problems society faces, and in order to evaluate possible solutions, you must have a little knowledge of chemistry. I hope that you don't get lost in the smog!

Finally, I introduce you to nuclear chemistry, with discussions about radioactivity, carbon-14 dating, fission, and fusion nuclear reactors.

Part 5: The Part of Tens

In this part, I introduce you to ten great serendipitous chemical discoveries, ten great chemistry nerds (nerds rule!), and ten useful tips for passing Chem I. I started to put in my ten favorite chemistry songs, but I could only think of nine. Bummer. I also include a chapter on ten common chemicals used today to help you understand how basic chemistry affects daily life.

Icons Used in This Book

If you've read other *For Dummies* books, you'll recognize the icons used in this book, but here's the quickie lowdown for those of you who aren't familiar with them:

TIP

This icon gives you a tip on the quickest, easiest way to perform a task or conquer a concept. This icon highlights stuff that's good to know and stuff that'll save you time and/or frustration.

REMEMBER

The Remember icon is a memory jog for those really important things you shouldn't forget.

WARNING

I use this icon when safety in doing a particular activity, especially mixing chemicals, is described.

EXAMPLE

This icon points out different example problems you may encounter with the respective topic. I walk you through them step by step to help you gain confidence.

TECHNICAL STUFF

I don't use this icon very often because I keep the content pretty basic. But in those cases where I expand on a topic beyond the basics, I warn you with this icon. You can safely skip this material, but you may want to look at it if you're interested in a more in-depth description.

Where to Go from Here

Where to go from here is really up to you and your prior knowledge. If you're trying to clarify something specific, go right to that chapter and section. If you're a real novice, start with Chapter 1 and go from there. If you know a little chemistry, I suggest quickly reviewing Part 1 and then going on to Part 2. Chapter 8 on the mole is essential, and so is Chapter 6 on gases.

If you're most interested in environmental chemistry, go on to Chapters 18 and 19. You really can't go wrong. I hope that you enjoy your chemistry trip.

1

The Basic Concepts of Chemistry

IN THIS PART . . .

If you are new to chemistry, it may seem a little frightening. I see students every day who've psyched themselves out by saying so often that they can't do chemistry. The good news: Anyone can figure out chemistry. Anyone can *do* chemistry. If you cook, clean, or simply exist, you're part of the chemical world.

I work with a lot of elementary school children, and they love science. I show them chemical reactions (vinegar plus baking soda, for example), and they go wild. And that's what I hope happens to you when you read this book and find out how interesting and important chemistry can be.

The chapters of Part 1 give you a background in chemistry basics. I show you how to do calculations and introduce you to the metric system. I tell you about matter and the states it can exist in, and I also talk a little about energy, including the different types and how it's measured. I discuss the microscopic world of the atom and its basic parts and explain how information about atoms is conveyed in the periodic table, the most useful tool for a chemist. And I cover the world of gases. This part takes you on a fun ride, so get your motor running!

IN THIS CHAPTER

- Defining the science of chemistry
- Finding out about science and technology
- Working out the scientific method
- Checking out the general areas of chemistry
- Discovering what to expect in a chemistry class

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. Mankind 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 phenomena — 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.

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.

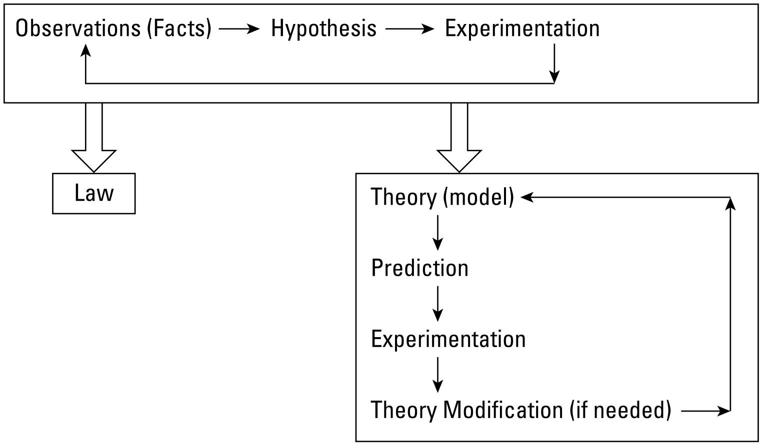

FIGURE 1-1: The scientific method.

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. He or she comes 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 he or she 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 mankind develops more advanced instrumentation and ways of examining nature, scientists may find it necessary to modify our theories or models.

SCIENCE FAIRS AND THE SCIENTIFIC METHOD

Suppose you're a high school student and your teacher is encouraging you to participate in the local science fair. You think and think about a project; you even buy *Science Fair Projects For Dummies* by Maxine Levaren (Wiley). A suggested experiment about energy content of nuts catches your eye and you decide to investigate which contains the most chemical energy — raw peanuts, roasted peanuts, or dry roasted peanuts. You think that nuts are roasted in oil so your hypothesis is that roasted peanuts contain more energy because of absorbed oil.

Now you have to design an experiment to test your hypothesis. You flip over to Chapter 10 on thermochemistry and read about calorimeters. You decide to make a calorimeter out of a couple of steel cans and a thermometer. You are careful to consider the variables involved — the mass of water, the mass of the nuts, and so on — and off you go to build your apparatus. You realize that you'll have to make several determinations on each type of peanut. You carefully and methodically collect your data, even doing an error analysis on the data.

After analyzing your data you may or may not have to modify your initial hypothesis. But then you begin to wonder if a cashew contains more energy per gram than a peanut — and what about all those other nuts in the grocery store? Your simple science fair project has generated more questions. And that is the road of the true scientists. Each investigation may answer some questions, but most probably will generate a lot more. Who knows, in 15 years you may find yourself working as a food chemist.

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. You even buy a new CD changer so that you can listen to hours of music while studying. After unpacking and hooking everything up, you notice that you have no sound coming out of the left speakers when a CD 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 CD changer, the receiver, or the cables connecting the two because everything else is working correctly. You form the hypothesis that something is wrong with the CD 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 CD player and the receiver are variables as well as 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 CD unit. 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?

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 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.

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 CD cable connections were swapped, either the CD changer 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.

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 material 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. It's 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.*
- **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 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 next 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 hydrogen 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. The 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. Theirresearch is directed toward a very specific short-term goal set by the company — product improvement or the development of a disease-resistant strain of corn, for example. 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 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 the 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 the 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.)

WHAT YOU CAN DO WITH A CHEMISTRY DEGREE

Although you're just into your first semester or year of chemistry, you may be envisioning a life in chemistry. You may be thinking that all chemists can be found deep in a musty lab, working for some large chemical company, but chemists hold a variety of jobs in a variety of places:

- **Quality control chemist:** These chemists analyze raw materials, intermediate products, and final products for purity to make sure that they fall within specifications. They may also offer technical support for the customer or analyze returned products. Many of these chemists often solve problems when they occur within the manufacturing process.
- **Industrial research chemist:** Chemists in this profession perform a large number of physical and chemical tests on materials. They may develop new products or work on improving existing products, possibly working with particular customers to formulate products that meet specific needs. They may also supply technical support to customers.
- **Sales representative:** Chemists may work as sales representatives for companies that sell chemicals or pharmaceuticals. They may call on their customers and let them know of new products being developed, or they may help their customers solve problems.

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- **Forensic chemist:** These chemists analyze samples taken from crime scenes or analyze samples for the presence of drugs. They may also be called to testify in court as expert witnesses.
- **Environmental chemist:** These chemists may work for water purification plants, the Environmental Protection Agency, the Department of Energy, or similar agencies. This type of work appeals to people who like chemistry but also like to get out in nature. They often go out to sites to collect their own samples.
- **Preservationist of art and historical works:** Chemists work to restore paintings or statues, and sometimes they work to detect forgeries. With air and water pollution destroying works of art daily, these chemists preserve our heritage.
- **Chemical educator:** Chemists working as educators may teach physical science and chemistry in schools. University chemistry teachers often conduct research and work with graduate students. Chemists may even become chemical education specialists for organizations such as the American Chemical Society.

These professions are just a few that chemists may find themselves in. I didn't even get into law, medicine, technical writing, governmental relations, or consulting. Chemists are involved in almost every aspect of society. Some chemists even write books.

IN THIS CHAPTER

- Getting acquainted with the SI measurement system
- Finding out how to work with really big and small numbers
- Understanding accuracy and precision of measurements
- Solving unit conversion problems
- Coping with significant figures

Chapter 2
Contemplating Chemical Calculations

Chemistry has a lot of calculations. But they're nothing you can't handle — they're arithmetic and simple algebra. To help you get a firm grasp of the calculations you encounter, you need to know a few important things.

You need to be familiar with the measurement system chemists use, the SI system (probably better known to you as the metric system). You also need to know a very useful way of setting up a problem — the unit conversion method. Along the way, you also need a good understanding of significant figures and rounding off. All in all, this chapter has a bunch of math, but hang in there. Mastering the basics here can help you as you venture through this book and through any chemistry courses you take.

Grasping the SI Measurement System

Much of the work chemists do involves measuring physical properties, such as the mass, volume, or length of a substance. Because chemists must be able to communicate their measurements to other chemists all over the world, they need to speak the same measurement language. This language is the SI system of measurement (from the French *Systeme International*), related to the metric system, which you hopefully have used before. Minor differences exist between the SI and metric systems, but for the most part, they're very similar.

This section lists the SI prefixes, base units for physical quantities in the SI system, and some useful SI-to-English measurement conversions.

Eyeing the basic SI prefixes

In order to be able to correctly use the SI system, you need to have a firm understanding of what each prefix means. The good news: The SI system is a decimal system. In other words, it's easy to use as long as you know the prefixes.

SI has base units for mass, length, volume, and so on, and prefixes modify the base units. For example, *kilo-* means 1,000; a kilogram is 1,000 grams, and a kilometer is 1,000 meters. Use Table 2-1 as a handy reference for the abbreviations and meanings of some selected various SI prefixes.

TABLE 2-1 SI (Metric) Prefixes

Prefix	Abbreviation	Meaning
tera-	T	1,000,000,000,000 or 10^{12}
giga-	G	1,000,000,000 or 10^{9}
mega-	M	1,000,000 or 10^{6}
kilo-	k	1,000 or 10^{3}
hecto-	h	100 or 10^{2}
deka-	da	10 or 10^{1}
deci-	d	0.1 or 10^{-1}
centi-	c	0.01 or 10^{-2}
milli-	m	0.001 or 10^{-3}
micro-	µ	0.000001 or 10^{-6}
nano-	n	0.000000001 or 10^{-9}
pico-	p	0.000000000001 or 10^{-12}

Units of length

The base unit for length in the SI system is the *meter.* The exact definition of meter has changed over the years, but it's now defined as the distance that light travels in a vacuum in $\frac{1}{299,792,458}$ of a second. Here are some SI units of length:

1 millimeter (mm) = 1,000 micrometers (μm)

1 centimeter (cm) = 10 millimeters (mm)

1 meter (m) = 100 centimeters (cm)

1 kilometer (km) = 1,000 meters (m)

Some common English to SI system length conversions are

1 mile (mi) = 1.61 kilometers (km)

1 yard (yd) = 0.914 meters (m)

1 inch (in) = 2.54 centimeters (cm)

Units of mass

The base unit for mass in the SI system is the *kilogram*. It's the weight of the standard platinum-iridium bar found at the International Bureau of Weights and Measures. Here are some SI units of mass:

1 milligram (mg) = 1,000 micrograms (μg)

1 gram (g) = 1,000 milligrams (mg)

1 kilogram (kg) = 1,000 grams (g)

Some common English-to-SI-system mass conversions are

1 pound (lb) = 454 grams (g)

1 ounce (oz) = 28.4 grams (g)

1 pound (lb) = 0.454 kilograms (kg)

1 grain (gr) = 0.0648 grams (g)

1 carat (car) = 200 milligrams (mg)