NOVARE

3rd Edition

PHYSICAL SCIENCE

A MASTERY-ORIENTED CURRICULUM

John D. Mays

Novare

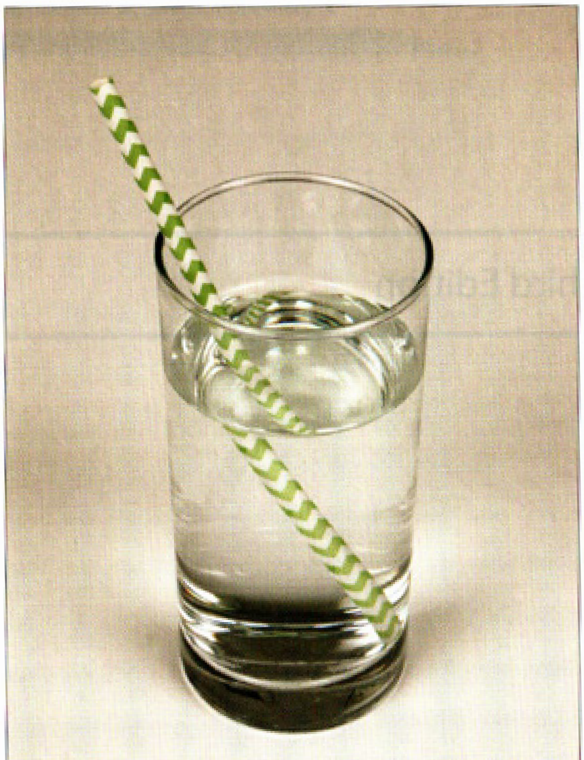
Physical Science

A Mastery-Oriented Curriculum

Third Edition

NOVARE
SCIENCE & MATH

Austin, Texas
2017



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DEDICATION

To the young people of today, growing up in a world that loves science but has lost sight of the point of it. May you have the eyes to see nature as an exquisite gift and the hand of the Divine Maker everywhere you look.

REVIEWER

This text was carefully reviewed for technical accuracy and clarity of expression by

Chris Mack	Adjunct Faculty, University of Texas at Austin PhD, University of Texas at Austin, Chemical Engineering MS, Electrical Engineering, University of Maryland BS degrees in Physics, Electrical Engineering, Chemistry, Chemical Engineering, Rose-Hulman Institute of Technology

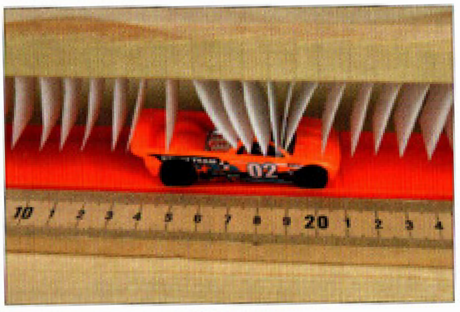
Any errors or ambiguities that remain are the responsibility of the author.

ACKNOWLEDGEMENTS

Special thanks to my brother, Jeffrey, for suggesting to me the fundamental structural idea behind this book. One small comment led to a revolution in my thinking about writing science textbooks. Thanks also to Gerald Tilma, who provided great skill in his work as copy editor. Thanks as always to Dr. Chris Mack, who loves to read and comment on what I write, and whose comments always lead to endless trains of thought. Any errors, omissions, or cloudy thinking that remain are my own fault.

Finally, thanks to my faithful wife Neda, who brings me a stunning work of art to eat for lunch every day. This book was built on salad.

Contents



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Teacher Preface

The book you have before you is clearly not a typical middle school physical science text. It is not two inches thick, it does not weigh five pounds, and it does not attempt to cover every topic in all of the physical sciences. These are not accidents.

I believe that science education, including textbook design, needs a major overhaul. The design philosophy behind this text represents my idea of where to start. My philosophy of pedagogy—and thus textbook design—is based on three core principles—*Mastery, Integration,* and *Kingdom Perspective*. I summarize these principles this way:

MASTERY

The norm for classes in contemporary schools is what I call the *Cram–Pass–Forget cycle*. Students cram for tests, pass them, and then forget most of what they crammed in just a few weeks. Teachers across the nation know exactly what this looks like because they see it day after day. This cycle is a waste of time for teachers and students. Instead, students should *learn, master,* and *retain* what they have learned. Realizing this in the classroom requires both the teacher and the students to make significant changes in the ways they approach the tasks of teaching, testing, practicing, and studying. For textbooks, a mastery orientation requires that the curriculum cover fewer topics, and cover them deeply. When students engage with content, their efforts should be directed at comprehension, practice, and retention of important concepts, not mere exposure to masses of material they will not remember. Methods that promote the Cram–Pass–Forget cycle must be replaced with more effective methods.

In a mastery-oriented learning environment, students notice that the workload is demanding, and initially some of them resist. But all the students learn far more than they do otherwise. They typically remember the material for years, and most of them—even those who aren't much interested in school—eventually come to recognize the value of such a learning experience. Some recognize this immediately, some only after they go off to college and find themselves ahead of their peers because of things they remember from many years before.

An example of how a mastery approach is realized in this text is in the use of unit conversions in computational exercises. Unit conversions and the SI System of units are introduced in Chapter 8. After that, all computations in Chapters 8, 9, 10, and 13 require students to perform unit conversions and to maintain their familiarity with the SI System units and prefixes.

For more information about how mastery concepts should be implemented with this text, see the "Notes on Using this Text" section below.

INTEGRATION

Effective science instruction requires that a number of content areas not usually represented adequately in curriculum materials be deeply embedded in the curriculum. These content areas include scientific process, basic epistemology, mathematics, scientific history, and English language usage. Typically, science classes do not place the necessary emphasis on these areas, and as a result, students fail to have a coherent and effective learning experience. Science teachers must think deeply about how their courses address the need for these and other key areas of integration and make adjustments to curriculum, teaching methods, assessments, and coordination between science courses.

An example of how integration is realized in this text is that the questions and exercises in every chapter and in every experiment require students to write out answers in complete sentences. This helps develop their ability to write well and to articulate scientific principles accurately. Another example is the introduction of graphical (and thus quantitative) presentation of data in the reports students write for the experiments. A third example is the way the discussion in the text builds toward Chapter 7, where students engage with different categories of knowledge and with the distinction between scientific claims and truth claims.

KINGDOM PERSPECTIVE

Science and mathematics provide us with unique ways of seeing God's creative presence in the world. Bringing biblical faithfulness to science classes is not accomplished simply by folding in a few Bible verses or prayers. In fact, much more is involved. Science and math teachers must think very broadly about how we fulfill Christ's mandate to love God with all our mind, how we teach our students effectively to engage issues, and how we perceive God's fingerprints in creation.

We also need to engage thoughtfully with the scientific claims of our day. It is not a scientific claim to say that the universe got here by itself; that is a metaphysical claim based on an atheistic worldview. But it is a scientific claim to say that the universe began with the Big Bang and is now 13.8 billion years old. The scientific evidence behind this claim is vast, and I believe an appropriate science text is one that teaches students productively to engage such claims. I do not believe it is appropriate to teach students to be dismissive of claims like this one simply because they do not line up with certain ways of interpreting Genesis. I say this as one who fully believes the Bible, who loves reading Genesis and the rest of Scripture, and who accepts the strong evidence for an old universe.

My ideas about all three parts of this core philosophy are described in more detail in my book *Teaching Science so that Students Learn Science*. This book and a more detailed description of our textbook philosophy may be found on our website, novarescienceandmath.com

LAB JOURNALS AND LAB REPORTS

The overall goal of experiment documentation for middle school students is to continue laying the foundation for writing full lab reports—from scratch—when they get to high school. The target is for students to begin writing full lab reports in 9th grade, and the standard for such reports is presented in my book *The Student Lab Report Handbook* (also available on our website). Toward that end, I believe lab reports at the middle school level should focus on students describing what they did, presenting their results, and engaging with the questions.

Part of integrating English language development into science instruction is accomplished through the use of lab journals. Each of the 12 experiments included in this text requires students to document their work in a lab journal. Details about using lab journals are in the section entitled "Getting Started with Experiments," as well as in the first chapter of *The Student Lab Report Handbook*.

In each of the Experimental Investigations, I pose questions for students to engage with as they consider their results and observations. I leave the specifics of the student reports up to the individual instructor; requirements should be based on the preparedness and background of the students in a given class.

Several of the Experimental Investigations require students to calculate the "percent difference." This is the same quantity most secondary science teachers refer to as the "experimental error." For my reasons for using different terminology, please refer to Appendix B.

CONDUCTING EXPERIMENTS

The instructions written in the Experimental Investigations are rather brief. To keep students from getting lost in the details, I did not include some of the information instructors need to have at hand. I do assume that students at this level are supervised by an adult for the experimental work.

Full details are available at no charge to instructors using this text. Simply contact us by email or phone and we will send it to you. Ask for the *Novare Physical Science Experiment Resource Manual*. The manual is supplied electronically, and includes detailed materials lists, parts costs and sourcing information for all supplies, sample experimental results, and more detailed information about how to conduct each experiment effectively. The Experiment Resource Manual is also included on the Resource CD for this text (available at novarescienceandmath.com).

Five of the 12 experiments require construction of special wooden or metal parts. We recognize that this may pose a difficulty for some students, primarily those who do not have access to tools for cutting wood and metal. Accordingly, we offer an experiment "parts kit" containing the special parts for these five experiments. (Note: The kit includes only the unique wooden and metal parts that require cutting and assembly. Ordinary materials and supplies that can be sourced elsewhere are not included.)

NOTES ON USING THIS TEXT

One of the major motivations behind the design of this text is for students to be delivered from the Cram–Pass–Forget cycle alluded to earlier. Compared to other texts, this book is small. An appropriate amount of content has been assembled for students to master in a single year of study.

But for mastery to be realized, certain practices need to be a regular part of the classroom experience. Regular review, rehearsal, and practice of older material must occur alongside the study of new material. Otherwise, students simply forget things a few weeks after being tested on them.

Here are a few specific practices that should be regularly present in classes using this text. These practices simply represent good teaching, and should be part of any well-structured course.

1. *Class Discussion* Discuss concepts, ask questions, and give students opportunities to express concepts in their own words. Use the "Learning Check" questions at the end of each section and the Chapter Exercises as questions to stimulate discussion. All these questions should be discussed in class. Take time with this type of discussion and don't hurry. This is why the book is modestly sized—so there will be adequate time for extended discussion and deep engagement with the material.

2. *Group Study* Divide students into groups for teamwork on answering some of the more difficult questions in the Chapter Exercises. Then have teams

take turns reporting their answers to the class. Stimulate discussion between teams about the merits of different answers to a particular question, and seek a class consensus on a well-formed answer.

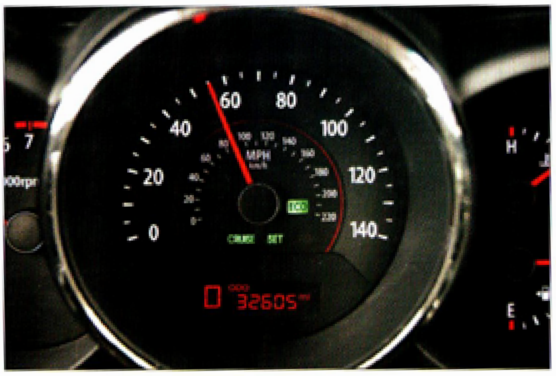
3. *Review Discussion* Go through questions again from past chapters. It is also fun to create competitions among teams in which teams score points by giving good answers to review questions. Some kind of activity like this should occur at least once every other week throughout the duration of the course.

4. *Review Computations* Once the computational exercises begin (Chapter 8), students should experience a steady stream of weekly review computations for the rest of the course. Once a new computation has been introduced, students should see new sets of problems containing similar computations to work as review every week. Correct answers should always be furnished with new review problems sets. Review problems should make frequent use of unit conversions using the metric prefixes from Table 8.4 and the conversion factors from Table 8.6. The *Resource CD* for this text contains Weekly Review Guides for this purpose.

5. *Enrichment Activities* Although concepts are covered thoroughly in the text, understanding is enhanced and memory is strengthened when students engage with the content in activities outside the text. Classes should incorporate full-length instructional videos, classroom demonstrations, hands-on play with models (such as for modeling molecules), internet images, You Tube videos, games, student presentations, projects, and other activities. Teachers should emphasize activities designed to make students *active* participants in the learning process, rather than simply passive observers. To assist with this, we have compiled a list of relevant short videos, images, and other resources, organized chapter by chapter. Look for the Tips and Tools link under the Extras tab on our website.

In addition to the comments here, more extensive information about the organization of chapter content and recommendations for teaching with this text are available on the Resource CD. Teachers are strongly encouraged to study that information in order to make the most of the pedagogical philosophy behind the design of this text.

Chapter 0
Start Reading Here



It seems to me that everyone should love the world of science and technology. After all, science is about studying this fascinating world that God made and we live in. Technology is the process of applying scientific principles to nature to solve particular engineering problems. These are really fun things to do.

Long before I was a science teacher, I was an engineer. I suppose I was in training my whole life to become an engineer. When I was a kid, I was always exploring the natural world. With my friends, we explored the woods and creeks near our home. We caught crayfish with a piece of bacon on the end of a string. We made dams in the gutters during rainstorms. We searched for interesting rocks and insects. We learned how to take care of a tortoise and how to pick up a snapping turtle without getting our fingers snapped off!

I was also learning how to build things (still one of my favorite things to do!). I built tree houses and model cars (a great number of each). I went to construction sites and talked to the workers to learn about what they were doing. I took my bicycle completely apart and put it back together. (It was hard to pedal after that—I didn't know how to tighten the wheels and pedals properly!) My friends and I built wooden go-carts (from scratch) that we could race down the hilly streets where we lived. When I was 10, I even built an elaborate work bench in our garage especially for building model cars.

I was also learning how to solve particular technical problems. As a Boy Scout who went camping every month for five years, I learned how to start a fire when the wood is soaking wet, how to start a fire without matches or a lighter, how to prevent our food from being destroyed by bears, how to sharpen a knife, how to carve things, how to make a lanyard and tie good knots, how to purify water so we didn't get sick, and how to find my way through a forest with a map and compass.

I could go on and on, but the point is this. It is really fun to explore the way the world works and to apply scientific principles to solve engineering problems. These are pretty much what this book is about. We are going to explore some of the fundamental principles of physics and chemistry—that's what the phrase *physical science* means. And in the 12 experiments, we see how these principles can be applied to the real world. The experiments all involve building or setting up some kind of apparatus using common materials, and that is both fun and interesting. And most of the experiments require you take make careful measurements—something that is challenging because it is not so easy as it sounds!

I hope you have a lot of fun with this study. Once you get hooked on exploring nature, the world just gets more fascinating and wonderful every year—and you can almost never get bored! If you do get hooked and want to become a scientist or engineer, that would be super. The world will never run out of problems to solve, and helping solve them is work that is open to just about anyone who is willing to put their mind to it—maybe even you!

And now for a note on how this science course is organized. I assume if you are reading this that you are around 11–14 years old. You are probably in 6th, 7th, or 8th grade. You probably love science and love studying about the amazing world we live in. I love these things too, and I love teaching students about this wonderful world.

I am sure that you have already been studying topics in science for several years. But now that you are in middle school, it's time for your studies in science to become a bit more organized. Do you like knowing how things fit together in the "big picture"? When you study a complicated topic in history or math, do you like to start from the beginning and build up your knowledge in a careful, organized way? For myself, I know that if I understand how things fit together—starting with the basics—it helps me understand and remember things better.

In this book, this is what we are going to do. When we talk about the "laws of nature," the laws of physics and chemistry, we can talk about the world of very tiny things, like atoms and molecules. We can also talk about the world of larger things like balloons, rockets, and machines. We can even talk about the world of *very* large things like planets and galaxies. For you to have a solid understanding about how the laws of nature work, we need to study *both* the small and the large. So in this book, we begin with some things science has discovered about the microscopic world. This will help you understand the fundamental principles that govern how the everyday world works.

Now we are ready to begin. Enjoy your study of our fascinating world!

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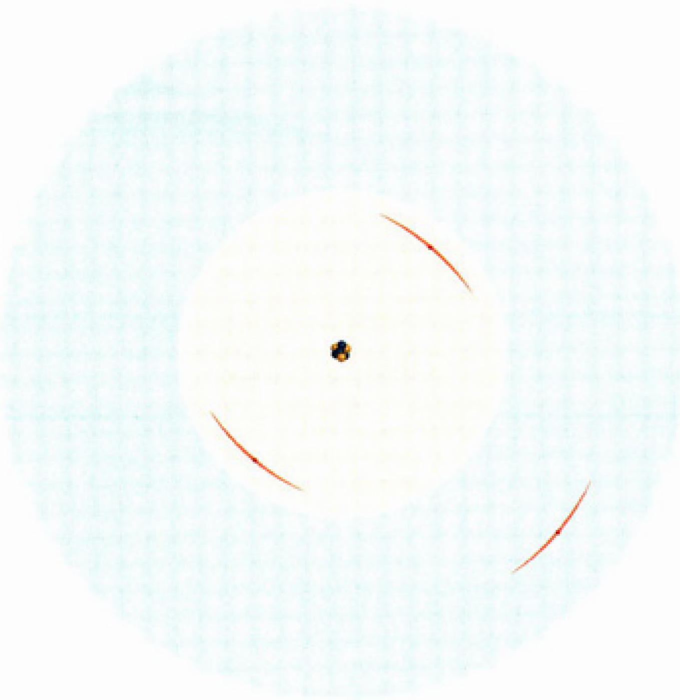
Chapter 1
Matter and Atoms



The drawing above is a depiction of a lithium atom. In the center is the atomic nucleus, containing four neutrons and three protons. In the much larger spherical regions surrounding the nucleus are the atom's three electrons, two in the inner region and one in the larger outer region. To make the nucleus visible at this scale, it is drawn about 2,500 times larger than it should be. If the nucleus were drawn to scale for a diagram of this size, it would be 1/300th the size of the period at the end of this sentence.

OBJECTIVES

After studying this chapter and completing the exercises, you should be able to do each of the following tasks, using supporting terms and principles as necessary.

1. Name and briefly explain the three basic things the universe is made of.
2. Describe how the particles in atoms are organized.
3. Describe each of the three basic subatomic particles.
4. Describe the atomic models developed by John Dalton, J.J. Thomson, Ernest Rutherford, and Niels Bohr.
5. Describe the key features that the quantum model of the atom added to correct and complete the Bohr model.
6. State the contributions of Democritus and James Chadwick to atomic theory.

VOCABULARY TERMS

You should be able to define or describe each of these terms in a complete sentence or paragraph.

1. atom
2. charge
3. electron
4. energy
5. intelligence
6. ion
7. mass
8. matter
9. neutron
10. nucleus
11. orbital
12. proton
13. shell
14. subatomic particle
15. volume

1.1 The Three Most Basic Things

What are the pages of this book made of? Paper, of course, but what is paper made of? The answer is that paper is made of the fibers from various kinds of plants, including trees. But what are these fibers made of at the most basic level? You probably already know the answer—*atoms*. The material stuff in the every day world is made of atoms, parts of atoms and a few other strange particles we can't see.

Matter is just our word for substances made of particles that have *mass* and take up space (have *volume*). The matter we normally encounter is made of atoms. There are different ways the atoms can be arranged, such as crystals and molecules. There are also different forms matter can take, depending on how hot or cold it is. We will discuss these things in more detail later. Our point here is that matter is one of the three basic ingredients that form the universe we live in.

All matter is substance that has mass and volume.

Matter is one of the basic things the physical universe is made of. But matter is not all there is in the physical world. Going back to the pages of this book—how did the pages get here? How were they fashioned, printed and bound? And thinking even more deeply, what holds the pages together? Why don't their atoms fly apart, like spray paint coming out of a can?

The answer to these questions relates to *energy*. The pages of this book were fashioned into their present form through the use of energy. The machines that cut the trees, the factory that made the paper, and all the people involved in making the paper and the book used energy to do their work. But thinking more deeply again, the atoms in the pages are sticking together because of the energy in their attractions for each other. The atoms *themselves* are held together by energy. Nothing anywhere can happen without energy being involved, and energy itself is what holds everything together.

Energy holds everything together and enables any process to happen.

Some scientists are content to say that matter and energy are the two basic ingredients of which the universe is made. However, there is one more basic ingredient that must not be left out. I am going to call that ingredient *intelligence*.

The pages of this book did not get into their present form just by a random surge of energy. Someone—or actually, some people—with intelligence used many different processes, machines, and materials to fashion these pages into their present form. There is no way the pages could have come together into this nice little book without the intelligent contributions of all those people (including me, the writer). And looking more deeply here once again, intelligence is not just a characteristic animals and humans have. Intelligence is *all over the place* in all of nature. In the materials used to make this book, there is intelligence behind the laws of physics that govern the inner workings of the atoms. There is intelligence in the laws of chemistry that govern the chemicals in the trees used for the pages and the pigments used in the ink. And there is an amazing and very sophisticated intelligence behind the DNA molecules that govern how the trees grow.

Nothing that we see around us could have gotten here without intelligence. Some of the things around us, like this book, got here through the intelligence of human beings doing their work. But think about the intelligence governing the laws of physics and chemistry. What is the source of the intelligence that governs chemical reactions and growing trees? The answer, of course, is that the intelligence behind these things is the intelligence of our Creator, the God who made everything and said that it was good.

Intelligence is the wisdom from God or his creatures that makes things work in an orderly and beautiful way.

To summarize this first section, all material objects—all matter—is made of atoms. Energy is present in nature, holding everything together and enabling everything to happen. And intelligence is present in the laws of physics and chemistry and in the use of matter and energy to make things. We will consider energy and intelligence in more depth in later chapters. Our task for the rest of this chapter is to consider atoms in more detail.

Learning Check 1.1

1. Describe the three basic things the universe is composed of.
2. Give an example of how intelligence is evident in nature.
3. In the list below, some things are clearly the result of human intelligence, and some are the result of the intelligence embedded in the laws of nature by God. Explain which is the case for each item.
   - an artist's painting
   - the arrangement of pieces of confetti on the floor at a party
   - the shape of a wadded up piece of paper
   - the design of the pages in a book
   - the arrangement of all the leaves in a tree
   - the sound of a cello string when it is plucked
   - the arrangement of the keys on a computer keyboard

1.2 Atoms

Chances are that you have learned about atoms before, so you may already have an idea of how they are put together. In this section, I am going to describe some basic scientific facts about atoms. Later, we will take a brief look at how scientists figured these things out.

Atoms are much too small to see. In order to see an object with our eyes, the object has to be big enough to reflect light waves into our eyes. But atoms are much smaller than the waves of visible light, so they do not reflect the waves, and we cannot see the atoms. What we know about atoms we have *inferred* from thousands of experiments. To infer something is to figure it out from the evidence. If I go out to my car and find the back bumper smashed, I infer that someone hit my car, even though I was not there to see it.

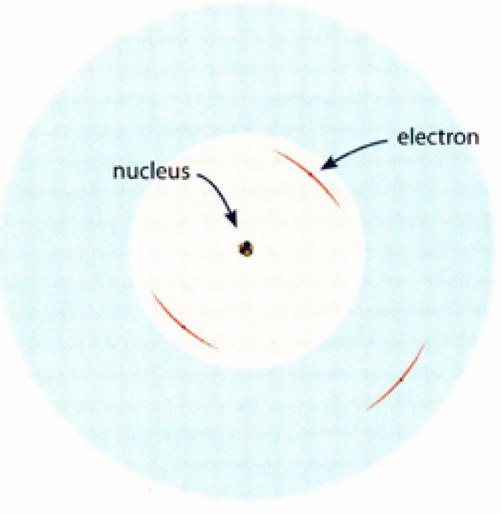


Figure 1.1. An atom with its nucleus of protons and neutrons, and electrons in a much larger region surrounding the nucleus. The nucleus is actually much smaller than shown in the picture.

Figure 1.1 is a diagram of a small atom, the way scientists currently understand them. In the center is the *nucleus* (which is actually much smaller than shown in the figure). Within an

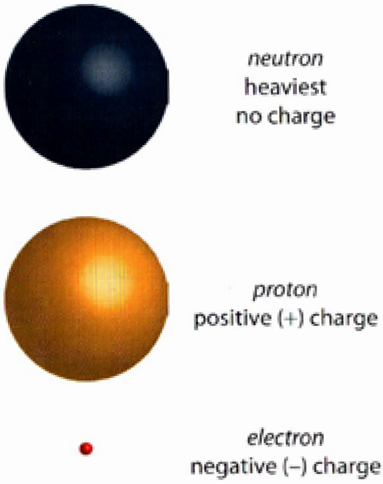


Figure 1.2. The three subatomic particles.

atom are three different types of *subatomic particles*, depicted in Figure 1.2. There are two kinds of subatomic particles in the nucleus: protons and neutrons. These particles have almost the same weight, although neutrons are a tiny bit heavier. Protons have a property called *charge*. This property is responsible for electricity and everything electrical in nature. There are two kinds of charge, which we call positive and negative. (Benjamin Franklin was the first to call charge by these terms, back in the 18th century.) The charge on protons is positive. Neutrons have no charge.

A third particle inside the atom is the electron. Electrons weigh about 2,000 times less than protons. This means that their weight almost does not matter. But what does matter is their charge, which is exactly the same strength as protons, but negative. The electrons buzz around in a sort of layered cloud around the nucleus. More on electrons in a moment.

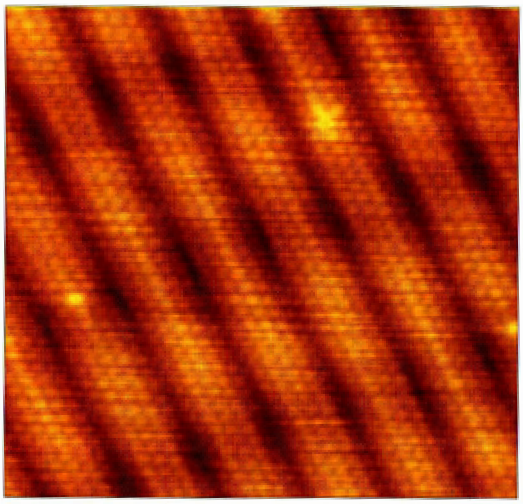
Other than the nucleus and the electrons, the rest of the atom is *completely empty space*. This is actually a bit mind boggling, so here is an example to help you visualize this. Figure 1.3 shows an engraving of the ancient sports stadium in Rome called the Coliseum. The tiny figures on the ground near the center of the Coliseum are people. Imagine that one of those people has a flower pinned to his lapel. If the nucleus of an atom were the size of the head of that pin, the cloud where the electrons are would be the size of the entire Coliseum! Everything else in the atom is empty space—nothing in there, not even air. (Of course, air is also made of atoms.)

Finally, when we speak of an atom alone by itself, we typically assume the atom is *electrically neutral*. This means that there is no net charge on the atom. The only way this can be is if the atom has an equal number of protons and electrons so that their charges balance out.

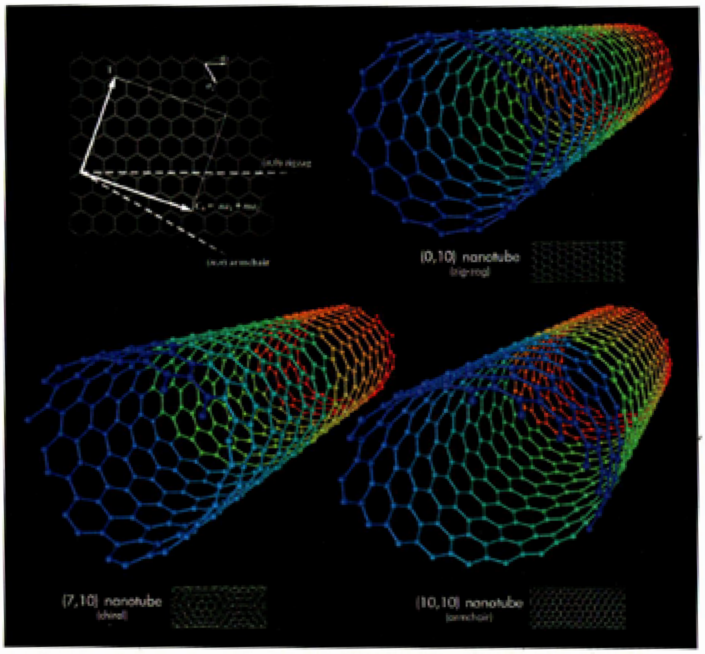
Figure 1.3. Engraving of the Roman Coliseum by Giovanni Piranesi.

It's pretty easy for most atoms to gain or lose electrons. When they do, they are not electrically neutral any more. They have a net charge, either positive or negative. Atoms with a net charge like this are called

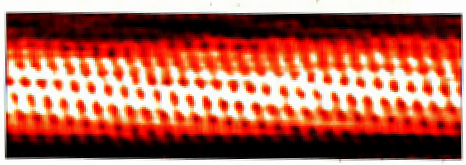
Scientists, Experiments, and Technology



Although atoms are too small to be seen, there are technologies that can make images of atoms we can study. The image to the right was made by a scanning tunneling microscope (STM) and the individual atoms are imaged as little circles. The STM uses beams of electrons reflecting off objects to construct an image of the object's structure at a very small scale. This image shows the surface of a sample of gold. The atoms inside a sample of gold are arranged in a regular, repeating pattern—rows of atoms without gaps. But at the surface, gold atoms can have a gap between the rows that occurs after every five rows of atoms.



In recent years scientists have been learning how to construct materials with very specific arrangements of atoms. A fascinating example is carbon nanotubes, represented in the computer image to the right. These are hollow tubes of carbon atoms with walls one atom thick. The diameter of a nanotube is about seven times the diameter of the carbon atom itself, and the tubes are extremely strong. An STM image of a nanotube is shown to the right.



ions. Ions with opposite charges attract each other. In later chapter, we will see that this is one of the main reasons atoms stick together to form chemical compounds.

Learning Check 1.2

1. Explain why scientists can claim that atoms exist, even though atoms cannot be seen.
2. Describe the locations of the three types of subatomic particles found in atoms.
3. Describe which subatomic particles have charge and which do not. For those that do, identify which kind.
4. Compare the weights of the three subatomic particles.
5. Explain what ions are and how they form.

1.3 Electrons

Let's talk just a bit more about the electrons and how they are arranged inside the atom. First, you need to know that electrons are *weird*, and it is hard to say just exactly what they *are*. Even though we refer to them as particles, they are certainly not hard little things like pellets or B-Bs. Electrons sometimes act like tiny particles, but they also sometimes act like *waves*. This is hard for everyone to understand, but that's just how it is. We all have to live with the strange properties of electrons and just try to understand them the best we can. Another thing about electrons is that there is no way to know precisely where they are and how fast they are going at the same time. This is why I drew the red streaks around the electrons in Figure 1.1. By showing them as sort of smeared, I am trying to show the uncertainty we have about where they are or how fast they are moving.

In an atom, every electron has a very specific amount of energy. The electrons are arranged in the atom according to how much energy they have. The clouds they buzz around in are called *orbitals* or *shells*. Electrons with the same amount of energy go in the same orbital, but only two electrons can go in each orbital. The large spheres in Figure 1.1 represent the first two orbitals that every atom has. Figure 1.4 shows the shapes of the first five orbitals every atom has, beginning with the two spherical ones. After the first two, the next three are shaped in a double arrangement that looks like a thick hamburger bun. The orbital shapes get even weirder after that, as you may learn later when you take chemistry in high school.

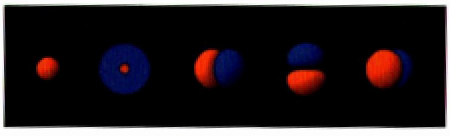


Figure 1.4. The first five orbitals in an atom. Each one can hold up to two electrons.

Learning Check 1.3

1. State at least five facts about electrons.
2. Describe the shapes of the first five electron orbitals in atoms.

1.4 The Development of Atomic Theory

Our theories about atoms have been under development for a long time. Over the centuries, there have been scores of important scientists who contributed key insights to our present theory—or model—of the atom. Here we will look at a few of the most important developments along the way.

The ancient Greek philosopher Democritus is usually given credit for first imagining that matter is made of atoms (Figure 1.5). Democritus lived in the 5th century BC, and proposed that everything was made of tiny, indivisible particles. The word atom comes from the Greek word meaning *indivisible*. For over 2,000 years after Democritus, nothing much happened to further our understanding of atoms. But then the scientific revolution began to take off, and major developments began to occur regularly.

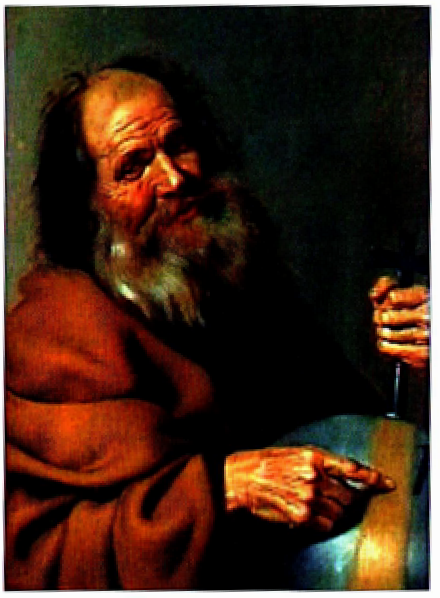


Figure 1.5. Greek philosopher Democritus.

In 1803, English scientist John Dalton (Figure 1.6) published the first fully scientific model of the atom. Dalton's theory included the idea that everything was made of indivisible atoms, as Democritus had said. Dalton went on to say that atoms combine together in whole-number ratios to form the compounds that different substances are made of. Dalton also proposed that atoms are not created or destroyed during chemical reactions, and that every atom of a given element is identical. All the points in Dalton's theory were either correct or partially correct, and Dalton's model was a major step forward.

Dalton's 1803 atomic model: indivisible particles.

Figure 1.6. English scientist John Dalton.

Dalton's model was not correct about the notion that atoms are indivisible. The first news

Figure 1.7. English scientist J.J. Thomson.

that atoms had smaller pieces inside them came from the work of another English scientist, J.J. Thomson (Figure 1.7). In 1897, Thomson performed a brilliant series of experiments that produced beams of electrons inside a glass tube. At the time, no one knew anything about electrons, but Thomson took the bold step of proposing that the beams he had produced were made of particles that came from within atoms.

Thomson's 1897 atomic model: the Plum pudding model—a cloud of positively charged material with thousands of negatively charged particles embedded in it.

As a result of his work, Thomson proposed a new atomic model, one that everyone now calls the *plum pudding model*. Now, most American students these days don't know much about plum pudding, so you can think of Thomson's model as the "watermelon model." As illustrated in Figure 1.8, Thomson modeled the atom as a cloud of positively charged material with thousands of negatively charged particles embedded in it, like a watermelon with its many seeds.

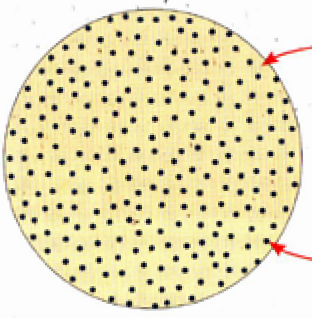


Figure 1.8. Thomson's "plum pudding" model of the atom.

The next scientist to develop a new atomic model was New Zealander Ernest Rutherford, (Figure 1.9).

Rutherford's 1909 atomic model: a tiny nucleus containing the positive charge and almost all the mass; negative electrons surrounding the nucleus; most of the atom is empty space.

In 1909, Rutherford was in England experimenting with firing small, positively charged particles at a thin foil made of pure gold. This work led Rutherford to conclude that all the positive charge in an atom is concentrated in the center, not spread out as Thomson had proposed. Rutherford called this central concentration of charge the *nucleus*. Rutherford also proposed that the electrons discovered by J.J. Thomson were outside the nucleus, surrounding it, and that most of the atom was empty space.

As you can see, with Rutherford's work we have come a long way towards understanding atoms, and we now have a general idea of how they are structured. The

The 1913 Bohr model: Building on Rutherford—electrons orbit the nucleus like planets. The energy of the electron determines its orbit, and only fixed energies are possible.

next development was put forward by Danish physicist Niels Bohr in 1913 (Figure 1.10). Bohr was the first to propose that the electrons were orbiting the nucleus like planets orbiting the sun. As depicted in Figure 1.11 on page 12, Bohr theorized that the orbits represented different "energy levels" for electrons. Lower energies were closer to the nucleus and higher energies were farther out. The lower-energy orbits would fill up first. The lowest orbit could hold two electrons. Orbits two and three could each hold eight electrons, and there were higher-energy orbits after that.

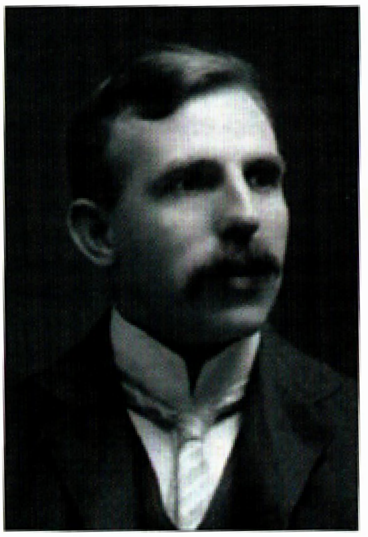


Figure 1.9. Physicist Ernest Rutherford, from New Zealand.

Bohr's model was very successful at explaining atomic behavior. However, it soon became clear that the electrons aren't exactly orbiting. Instead, an electron sort of zooms around—at extremely high speed—in a three-dimensional cloud defined by how much energy the electron has (as we saw back in Figure 1.4). And as we saw before, it is difficult even to think of electrons as particles at all, since they also have wave-like properties. One scientist said that since we don't really know what electrons are, we should just call them *slithy toves*. And when we talk about what they do, we can just say they *gyre and gimble in the wabe*![1]

Figure 1.10. Danish physicist Niels Bohr.

Our short history of the atomic model would not be complete without mentioning the discovery of one final important piece to the puzzle. In 1932, English scientist James Chadwick discovered the neutron. Scientists already knew that nearly all of the atom's mass was in the nucleus, along with all the positive charge. But what they knew about mass and charge didn't match up until Chadwick demonstrated that there were electrically *neutral* particles, also in the nucleus, that had almost the same mass

The quantum model: Building on Bohr—electrons reside in orbitals of various shapes nested around the nucleus.

1 In case you have forgotten, these terms are from the poem "Jabberwocky," in Lewis Carroll's *Through the Looking-Glass, and What Alice Found There.*

(slightly more) as the protons. With Chadwick's discovery our basic understanding of the atom was complete.

Scientists learned much more about atoms from experiments conducted throughout the 20th century. Our current model of the atom is called the *quantum model*. As I describe at the beginning of the chapter, the quantum model places the electrons in orbitals, rather than orbits. The quantum model describes the shapes of all the orbitals, and the rules governing which electrons go where among an atom's orbitals. These rules are at the heart of chemistry, which is all about how the electrons in atoms interact with each other. We will leave the rest of the details of the quantum model for another science course.

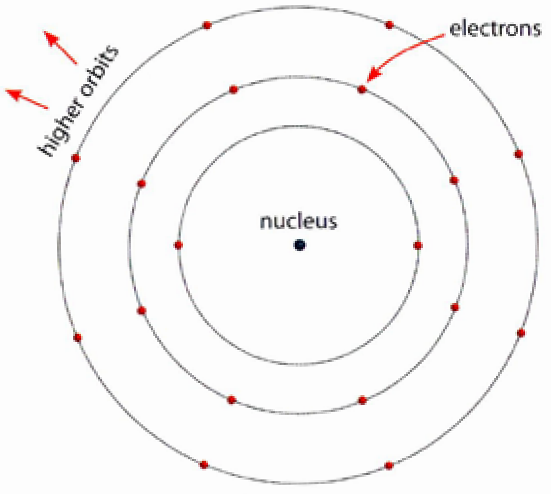


Figure 1.11. Bohr's planetary atomic model.

Learning Check 1.4

1. Describe the atomic models proposed by Dalton, Thomson, Rutherford, and Bohr.
2. Describe the additional features included in the quantum model.
3. Why did one scientist use the silly language of "Jabberwocky" to describe electrons?

Scientists, Experiments, and Technology

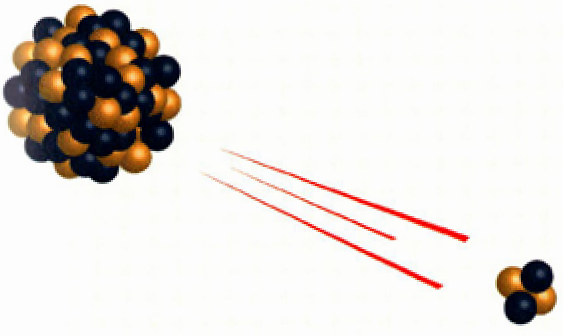
The particles used by Ernest Rutherford to explore the thin gold foil in his research are called *alpha particles*. Alpha particles (often written as α-particles) are a form of nuclear radiation. Each alpha particle contains two protons and two neutrons. Alpha particles are emitted naturally as radioactive substances go through the process called *nuclear decay*. The image on the opposite page depicts a large nucleus emitting an alpha particle during nuclear decay. When this decay happens, the alpha particles typically exit the atomic nucleus at a speed of 15,000,000 meters per second!

Alpha particles are sometimes used in common technologies such as smoke detectors. But I would rather tell you about a new technology being

Scientists, Experiments, and Technology (continued)

explored by researchers today. This technology is a cancer treatment called *unsealed source radiotherapy*.

The idea is to make use of the fact that though alpha particles will damage tissue, they do not penetrate the tissue very deeply. In unsealed source radiotherapy, small amounts of a radioactive substance are introduced into the body and directed near the site of a cancerous tumor. As the radioactive substance decays, the alpha particles it emits bombard the tumor and destroy it. Of course, the healthy tissue surrounding the tumor is also hit by the alpha particles. But because the alpha-particles do not penetrate the surrounding tissue very far, the healthy tissue is damaged only slightly. The damaged tissue will heal. The important thing is that the life-threatening cancer is destroyed.



Chapter 1 Exercises

Answer each of the questions below as completely as you can. Write your responses in complete sentences.

1. Describe J.J. Thomson's contributions to the development of the atomic model.
2. When scientists say that atoms are mostly empty space, what do they mean? (How empty are they, and what's in the empty part?)
3. Describe the particles found in the nucleus of atoms.
4. What determines where the electrons are in an atom?
5. Why was John Dalton's atomic model so important?
6. Describe the three basic ingredients the universe is made of.
7. What are some of the properties of electrons?
8. What are some examples from nature that indicate that an intelligent Creator made the world?
9. Describe the atomic model proposed by Ernest Rutherford.
10. What are *orbitals*?

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