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A Mastery-Oriented Curriculum

Third Edition

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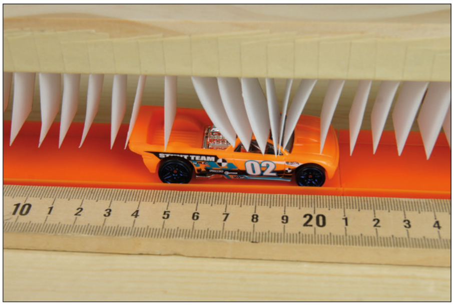
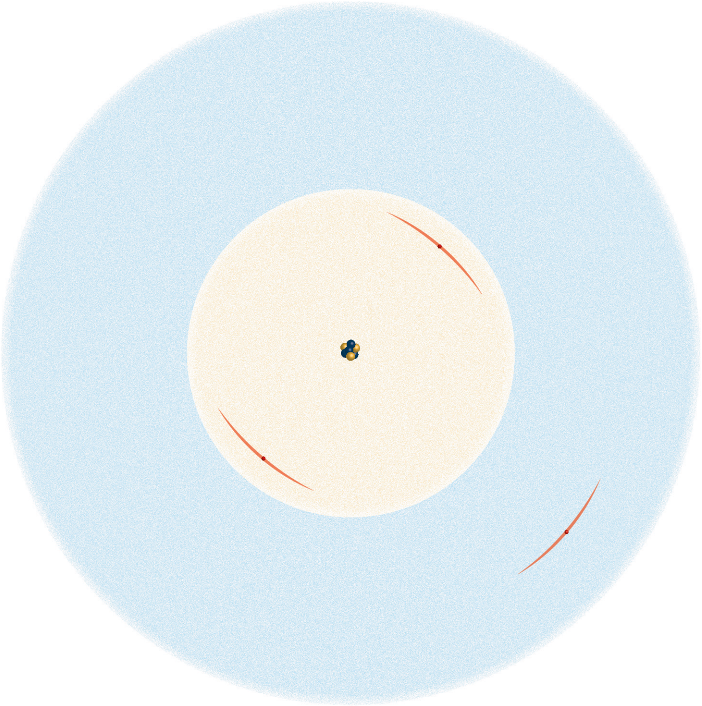


NOVARE
SCIENCE & MATH

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?

Energy holds everything together and enables any process to happen.

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.

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.

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

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.

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.

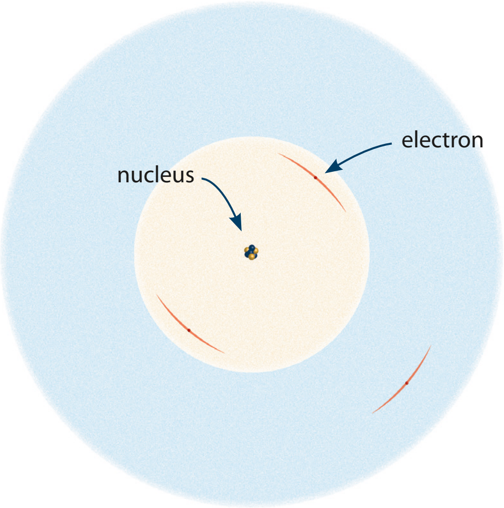


Figure 1.1. An atom with its nucleus of protons and neutrons, and electrons in a much larger region surrounding the nucleus. The nucleus is actually much smaller than shown in the picture.

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

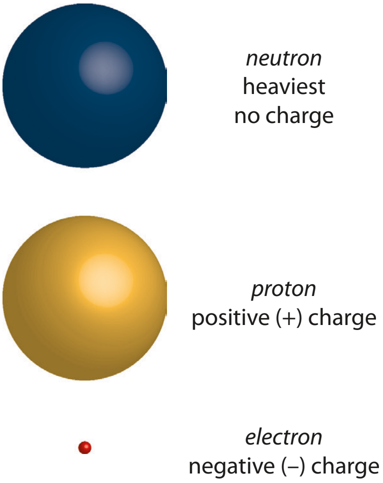


Figure 1.2. The three subatomic particles.

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.

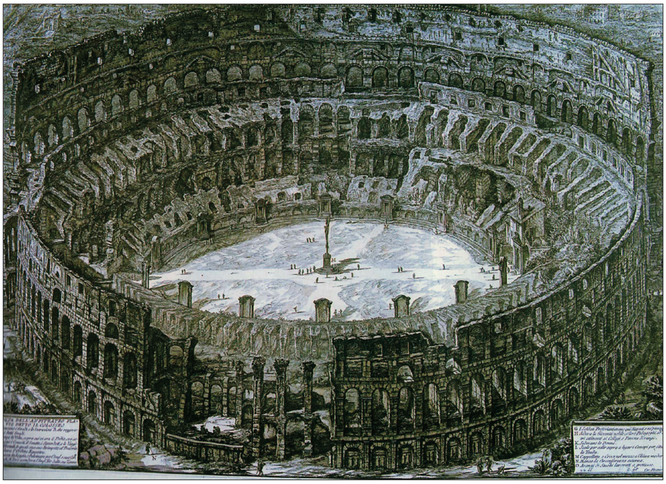
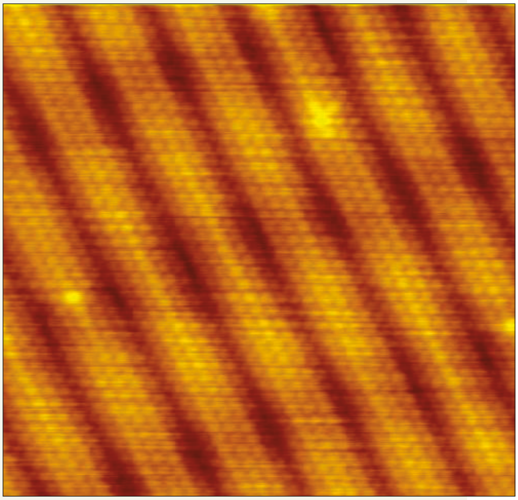


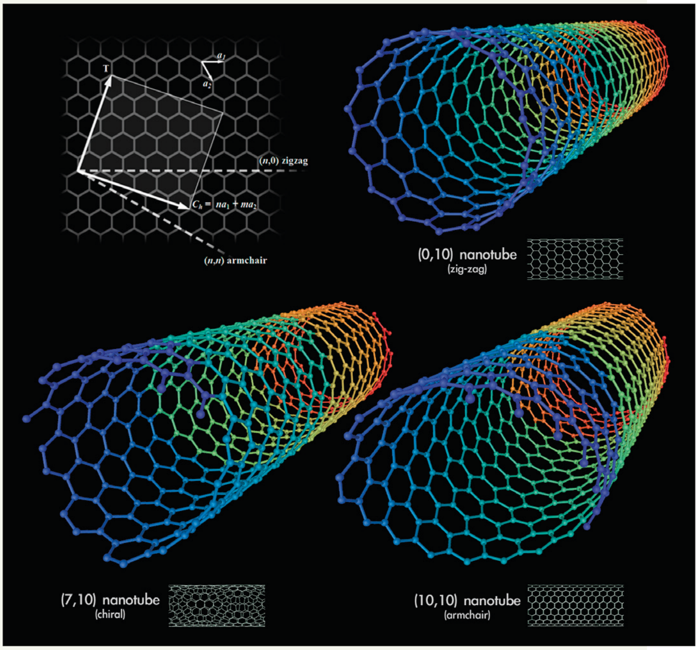
Figure 1.3. Engraving of the Roman Coliseum by Giovanni Piranesi.

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

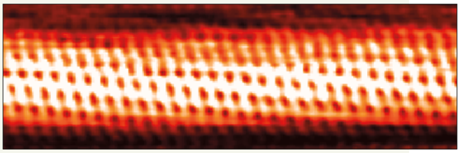
Scientists, Experiments, and Technology



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.

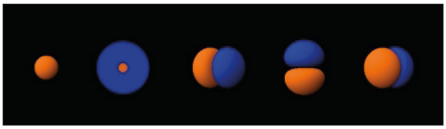


Figure 1.4. The first five orbitals in an atom. Each one can hold up to two electrons.

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.

Figure 1.5. Greek philosopher Democritus.

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 1.6. English scientist John Dalton.

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.

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

Figure 1.7. English scientist J.J. Thomson.

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

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.

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.

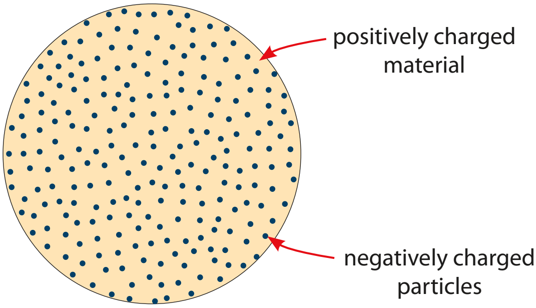


Figure 1.8. Thomson's "plum pudding" model of the atom.

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

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.

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.

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

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

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[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.

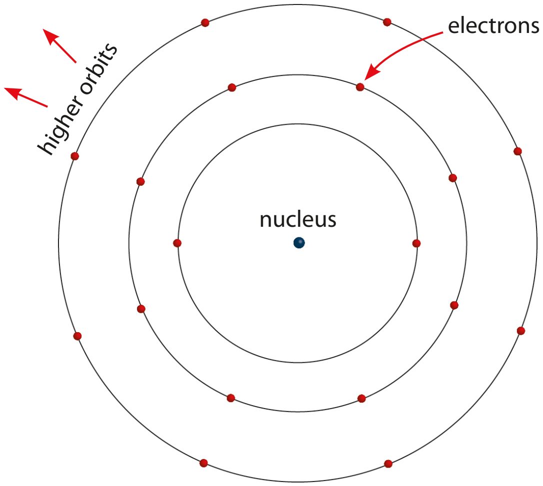


Figure 1.11. Bohr's planetary atomic model.

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

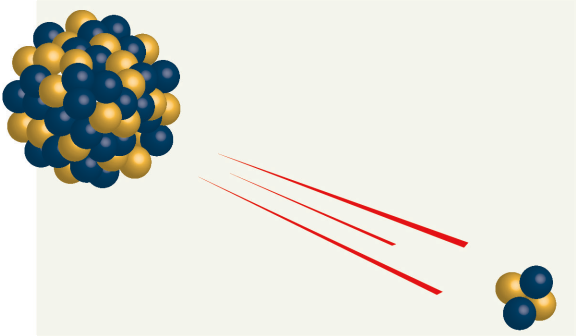
The particles used by Ernest Rutherford to explore the thin gold foil in his research are called *alpha particles*. Alpha particles (often written as α-particles) are a form of nuclear radiation. Each alpha particle contains two protons and two neutrons. Alpha particles are emitted naturally as radioactive 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*?

Getting Started with Experiments

The Art of Experimental Science

Experimental research is one of the things that makes science so interesting and so much fun. Science is a lot more than just learning things in books. Throughout the history of science, new discoveries have been made and new theories have been tested in the laboratory. If you are the type of person who loves fooling around with parts, wires, wood, and chemicals, then the experiments in this book will be right up your alley. If you are the type of person who would prefer to stay inside where it is air conditioned and drink tea, then the experiments will give you an opportunity to get your hands dirty. Who knows, you may find you love doing experiments! History is full of people—both men and women—who helped in a lab when they were 13, and ended up becoming experimental chemists or physicists. It could happen to you.

In the next few pages we will look at some of the important things to keep in mind while doing experimental work. I will conclude this introduction with a tutorial on preparing scientific graphs.

Safety

Safety is a major concern in any science laboratory, whether that lab is in a classroom, a research facility, your kitchen, or your garage. Here are some standard safety rules you should know and always follow:

1. Always wear safety goggles or safety glasses when heating substances on a hot plate or over a flame.
2. When handling hot substances or apparatus, use tongs or wear thermally protective gloves.
3. Use great care when handling glassware. As I always say, there are three ways to break something—improper procedures, silliness, or carelessness—and all are bad in a lab!
4. Wear protective eyewear and gloves when handling hazardous materials.
5. Always work under the supervision of a responsible and knowledgeable adult when using sharp tools, hot plates, flames, or chemicals.
6. Make sure you have a phone in your work area in case you ever need to call for help.

7. Always follow written procedures, and don't take short cuts. Do not revise procedures to suit yourself without consulting with a responsible and knowledgeable person who knows about the kind of work you are attempting to perform.
8. Never taste things in a science lab unless your instructor directs you to.
9. Always keep long hair tied back out of the way, and don't wear loose, blowsy, or baggy clothing while working in a lab.
10. Make sure you have adequate ventilation.
11. Make sure you have a fire extinguisher in your work area.
12. Exercise care in everything you do, pay attention, and avoid horseplay.

Care and Accuracy

It is common for those new to experimental work to underestimate just how careful one needs to be in order to get accurate results from a science experiment. Students' results are sometimes so inaccurate that they are useless, often requiring the students to do the work over again.

I have already mentioned that carelessness can be a safety hazard. But carelessness can also result in equipment that doesn't work properly, results that don't turn out correctly, or data that are useless. If your experimental data aren't any good, then you have wasted your time, and possibly your teammates' time as well.

So from the very beginning, make it your goal to follow directions carefully, to assemble apparatus with care and patience, and to record measurements with as much accuracy as possible. Resist the temptation to consider hastily or carelessly performed work as "good enough." Developing a passion for care and accuracy makes a big difference in the quality of your results. And when your results are superior, you learn more and you end up finding scientific experiments much more satisfying.

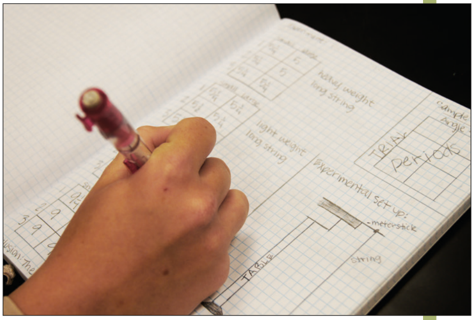
Doing It Over Is Okay

Sometimes, even when you are being as careful as you know how to be, experiments don't turn out the way they are supposed to. Welcome to the world of the scientist! How many thousands of light bulbs was it that Thomas Edison made before he found one that worked? Life in the science lab means sometimes things don't work. So let me offer you this advice and encouragement. When things don't work out right, just try to figure out how to improve your method and do the experiment, or part of it, over again. This may not be convenient; everyone is busy. But it is the right thing to do. If you have no idea what went wrong, then get some advice from someone who can help you figure it out.

Keeping a Lab Journal

Every practicing scientist maintains a *lab journal*, a written record of everything he or she does in the lab. As a science student, it is very important that you learn how to maintain your own lab journal, and that you faithfully document your work in it. Here's why lab journals are important in the real world:

- When work is being passed from one researcher to another, the journal is a record of what has been done in the past and how it was accomplished.
- When particular methods, equipment, or procedures used in the past need to be used again, the details are all in the lab journal.
- When people become famous, apply for patents, win awards, and so on, all the background information folks need in order to verify the work or write the scientist's biography is all there in the lab journal!



You may not invent something that needs to be patented, but you will need to write reports on your experiments, and to do that you need a record of what you did, who helped, when it happened, and what equipment you used. You also need a place to record your data. So when you do experimental work, always document everything in your lab journal. (Your teacher may even grade you on how well your journal is kept.)

Here is some advice about lab journals:

1. Keep your lab journal very neat and well organized. Don't doodle in it, draw in it, or mess it up.
2. Don't use a spiral notebook. Use a bound composition book with quadrille (graph) paper. (Quadrille paper makes it easy to set up tables and graphs.) Acceptable journals are the National 53-108, Mead 09100, and others available online and at office supply stores.
3. Put your name on it in case you misplace it.
4. For every experiment you work on, enter the following information:
    - the date (always enter the date again every day you work)
    - the names of team members working with you (enter these also every day you work, so you have a record of who is there and who is not each time you meet)
    - a *complete* list of all equipment, apparatus, materials and supplies you use in conducting the experiment
    - the manufacturer and model number for any electronic equipment you use
    - tables with *all* your data, with the original units of measure
    - calculations or unit conversions you perform as part of the experiment
    - observations or notes about anything that happens that you may need to write about in your report or remember later, including records of work that has to be repeated and why
    - methods or procedures you use, and the reasons for using them

There are other items you can enter in your journal that become more important as you get into high school and college (such as sources, contacts, and prices for special chemicals or parts you have to order), but the list above should cover the things that you need to worry about for now. Take pride in maintaining a thorough lab journal. Make it a habit always to have it with you when you work in the lab, and always to document your work in your journal.

Scientific Graphs

Graphs are extremely important in reporting scientific information. Often, a graph is the best way to present scientific information so that the reader can examine it and understand it most easily. Because scientific graphs are so important, many of the experiments in this text require you to prepare a graph for displaying your experimental results.

Depending on what grade you are in, you may have already learned about using Cartesian coordinates in graphs in your math class. If so, then learning how to prepare a proper scientific graph will be easy. But here I assume that some of the students using this book haven't studied graphing yet and I describe how to prepare scientific graphs in some detail. Even if you already learned how to make graphs in your math class, there are still many specific details about scientific graphs that you need to know. So read this section carefully.

We begin by considering an example experiment and some data from that experiment. We will use these data to illustrate how to set up and format a scientific graph.

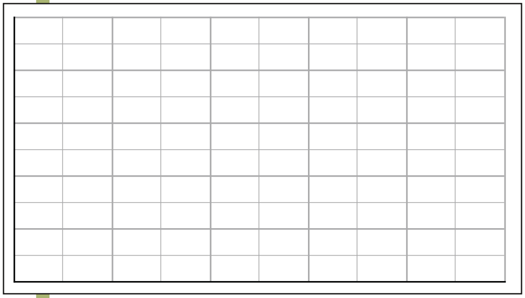
You may know that automobiles use water to keep the engine cool. You may also know that to keep the water from boiling in the summer or freezing in the winter, a product called *antifreeze* is mixed in with the water in the car's engine. I tested mixtures of water and antifreeze to see what the boiling point would be with different amounts of antifreeze mixed in. What I found is shown in the table to the right. (You probably know that plain water boils at 100°C. But you may not know that common thermometers are only accurate to +/− 1°C. This means that the reading might be off by one degree too high, or one degree too low. That is probably the explanation for why my boiling point was recorded as 101.0°C with plain water.)

Amount of antifreeze, by volume (%)	Boiling point (°C)
0	101.0
10	102.8
20	104.3
30	105.1
40	106.6
50	110.0

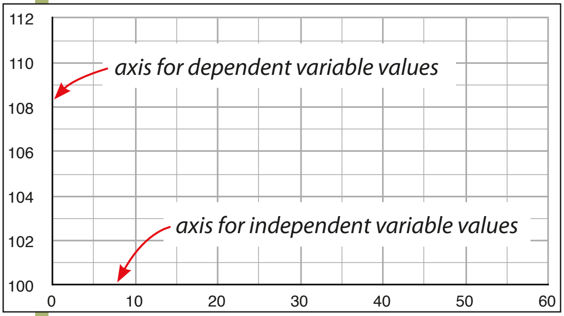
In this experiment there are two quantities we call *variables*. These variables are the amount of antifreeze in the mixture, and the boiling point of the liquid. Notice that it makes sense to think of one of these variables as depending on the other. I select the amount of antifreeze I put in the mixture and the boiling point that results depends on my selection. In the context of graphing scientific information, the variable the scientist selects values for is called the *independent variable*. In my example experiment, the amount of antifreeze in the mixture is the independent variable. The variable that depends on the scientist's selection is called the *dependent variable*, and in the example this is the boiling point.

A basic graph is a grid with a horizontal line across the bottom and a vertical line down the left side, as shown at the top of the next page. The two lines are called *axes*, and they are used as scales for locating the values of the variables for each data point (each row in the data table).

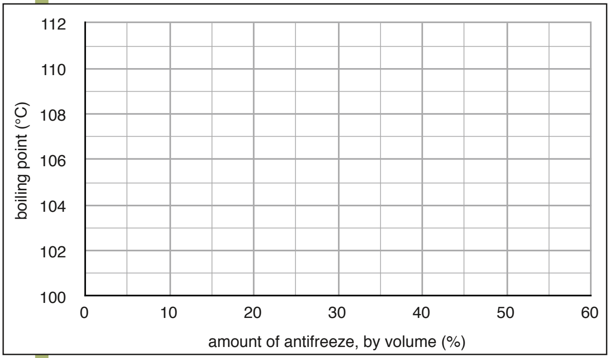
On a graph, we associate the independent variable with a scale marked out on the horizontal axis of the graph. We associate the dependent variable with the vertical axis of the graph. The first thing we have to do to set up the graph is decide what scales to use. Look again at the data values in the data table. As you see, the values for the independent variable, the antifreeze concentration, range from 0 to 50. We want to pick a scale that comfortably covers this range of values without having a great deal of excess space on either end. I am going to choose a scale that starts at 0 and goes up to 60, just a bit higher than the highest value.



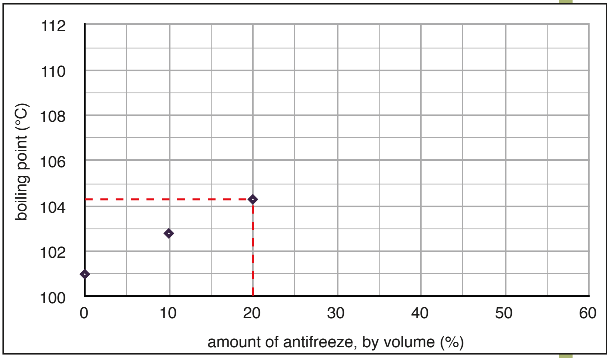
From the table, the values for the dependent variable, the boiling point, range from 101.0 to 110.0. So I will scale my vertical axis from 100 to 112. When I label the axes with these two scales, the graph looks like the illustration below. (Most of the time in math your axis scales probably start at zero. Well here's a little secret: they don't have to!)



The next thing we need to do is label each of the axes. The label must contain the variable associated with that axis, and the units of measure that go with it. In the third illustration I have added these labels. Notice that I placed the units of measure in parentheses. This is one of the standard methods of formatting the units and is the method you should use for now. Notice also that there are no capital letters in my labels. This is traditional for scientific graphs, and is the formatting I prefer for my students (although some scientific publications are now capitalizing the variable names).

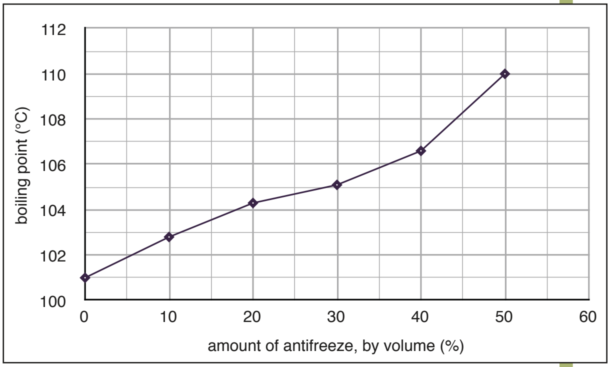


Now we are ready to locate each of the data points from the table on the graph. To do so, do the following for each of the data points (rows) in the data table. First, find the value of the independent variable on the horizontal axis, and using a ruler and pencil, draw a light vertical line from there up into the graph. Next, locate the value of the dependent variable on the vertical axis, and, using a ruler, draw a light horizontal line from there into the graph. Where these two lines meet is where you place some kind of symbol to represent that data point. In the next illustration, I depict this process for the third data point using dashed red lines. The first two data points are already shown on the graph.



Repeat the data point location process until all the data points from the data table are accurately located on the graph. Then connect each of the data points with a straight line, drawn with a ruler. The completed graph looks like the final illustration below.

There are a few final points to make. First, the type of graph I have shown how to make in this tutorial is called an *x-y scatter plot*, or simply *scatter plot*. There are many other types of graphs, but this one is the most important to know about. Scatter plots are used all the time in science to present data and other types of scientific information.



Second, if you are going to place your graph into a report, then your graph needs a title. Standard formatting for titles is to capitalize only the first letter of the first word, and to place a period at the end.

Third, until you get to some very fancy math in college, chances are that the scales on your graphs need to be *linear*. This means that the scales need to be marked in round numbers and regularly spaced. On my graph, the horizontal axis scale is marked in tens, spaced two lines apart. The vertical graph is marked in twos, two lines apart. The regular spacing is crucial in order for the graph to display the correct relationships between the data points.

Fourth, you don't always have to connect the dots in a graph, but it is common to do so.

Fifth, if you are displaying more than one data set on the same graph, you need to use different symbols or colors for the dots and lines of the different data sets. We run into this in Experimental Investigation 2.

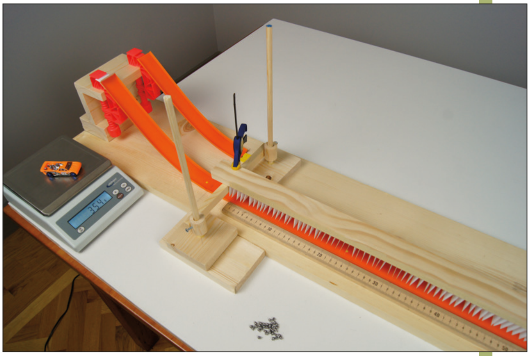
Finally, in high school you should begin learning how to prepare graphs on a computer. For now, your instructor may prefer that you concentrate on learning how to draw nice looking graphs by hand. (I think that is appropriate for middle school students.) But when drawing graphs by hand, make sure you a) use a ruler for the axes and for connecting data points, b) make the graph as neat as you are capable of making it, and c) locate your data points very accurately.

Now it's your turn!

Experimental Investigation 1: Kinetic Energy

Overview

- Using a Hot Wheels car and a ramp of Hot Wheels track, release the car from a standard height repeatedly, adding weights to the car each time to increase its mass. Measure the car's mass before each run.
- *The goal of this experiment is to determine how the kinetic energy of the car varies as its mass changes, assuming the car's speed at the bottom of the ramp stays the same.*
- Use an assembly of friction flaps and a measuring rule to slow the car and measure how far it travels while stopping. Use the stopping distance as a measure of the kinetic energy the car has at the bottom of the ramp.
- Verify that the speed of the car is not affected by mass by releasing two cars with different masses together.
- Collect mass and distance data, and prepare a graph of stopping distance versus mass.



Basic Materials List

- Hot Wheels cars and track
- lead weights (split-shot fishing sinkers)
- mass balance and measuring rule
- friction flap assembly of 3 × 5 index cards, and apparatus for adjusting its height
- apparatus for mounting the track

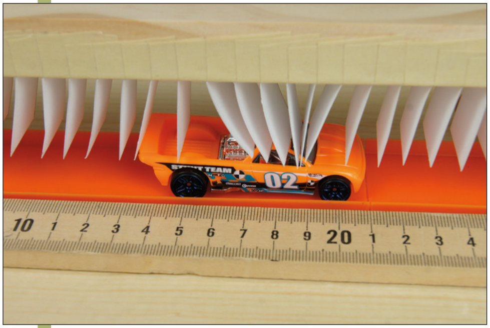
In the discussion of kinetic energy, you learned that the kinetic energy of a moving object depends on both the object's mass and its speed. In this investigation, we examine how increasing an object's mass increases the energy the object is carrying in its motion. This experiment will be fun because we get to use Hot Wheels cars! Your setup for this investigation is similar to the one shown above.

We start the car rolling by allowing it to roll freely down a track formed into a ramp. This is how the car gets its kinetic energy—the gravitational potential energy at the top of the ramp is converted into kinetic energy at the bottom of the ramp. Our setup allows us to increase the mass—and the kinetic energy—of the car without increasing its speed. We do this by releasing the car over and over from the same height, so that its speed at the bottom of the ramp is always the same (more on this in a moment). But each time we release the car, we increase its mass just a bit by adding small lead weights to the car. To enable this, we use a car with a cargo bed to hold the weights.

Note to Instructors

Full details on materials, preparations, and procedures for all the *Experimental Investigations* are available from the publisher (see Teacher Preface).

To get an idea of how much kinetic energy the car has at the bottom of the ramp, we make a device that uses friction to slow the car in a stopping zone. Our friction stopper uses flaps of index card to slow the car, and we gauge the amount of kinetic energy the car has by measuring how far into the stopping zone the car goes before the friction flaps bring it to a stop. The photo to the left shows a car being stopped by the friction flaps. The measuring rule next to the track allows the experimenter to measure how far the car travels into the stopping zone.



Let's go back for a minute to my comment that every time the car is released from the same height it will be going the same speed at the bottom of the ramp. Back in the 17th century, Galileo demonstrated that falling objects all accelerate at the same rate. This means that *any* object released from a given height above a table will be going the same speed when it reaches the table, regardless of its mass. Accordingly, our car will always be going the same speed at the bottom of the ramp, even as we add weight to it.

But rather than take Galileo's word for it, as part of this experiment you need to verify this for yourself. In the photo, you can see two ramps side by side. Before placing the friction flaps over the track, make a few trials with two cars released from the same height. Use two identical cars, and place weights in one of them to make it about 10–15% heavier than the other. As you do this, see if you can verify Galileo's discovery. In order to make this verification, you need to work out a way to release the two cars at exactly the same time.

For collecting experimental data, you use a single car. Adjust the height of the friction flap assembly so it is level, and so it stops the car before the car reaches the end of the track, even when the car is full of lead weights. Release it 3–5 times from the same height, adding another bit of weight to it each time. Vary the weight from a minimum (car empty), up to at least 130% of the car's empty weight. For each run, measure the car's mass and how far it travels into the friction/stopping zone, and record these data in a table in your lab journal.

Analysis

An important part of the analysis is to prepare a graph of stopping distance (vertical axis) versus mass (horizontal axis). Your instructor will help you with setting up your graph and labeling it properly. In your report for this experiment, address the following questions.

1. Were you able to verify that the car's speed at the bottom of the ramp didn't change, even as mass was added to the car? Describe how you did this.
2. How does the stopping distance relate to the car's kinetic energy? Use your graph to help address this question. Explain what caused the stopping distance to increase.
3. Where does the kinetic energy of the car go as the car stops?
4. What does the shape of your graph tell you about the relationship between kinetic energy and mass?

Chapter 3
Conservation of Energy

Sir Benjamin Thompson, also known as Count Rumford, was an American-born British physicist, inventor, and Christian believer. In the late 18th century, Thompson studied the heat produced during the process of boring cannon (drilling the hole down the center of a cannon after it is cast), and concluded that the heat was produced by the motion and friction of the drilling machine. His theory about heat was completely opposed to the prevailing view at the time, which held that heat was a substance inside objects. His ideas were foundational for the formulation of the law of conservation of energy a century later.

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. State the law of conservation of energy and give examples of its application.
2. Explain how friction on a moving object affects the forms of energy present in a given situation.
3. Explain Einstein's principle of mass-energy equivalence, and use the principle to explain the source of the energy in nuclear reactions.
4. Describe the three ways heat can transfer energy from one substance to another.
5. Explain how the heat radiating from a warm object can be used to determine the object's surface temperature.
6. Define *work*, and give examples of situations when work is or is not being performed.
7. Use the concept of internal energy to explain how a substance retains energy within its atoms or molecules.

VOCABULARY TERMS

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

1. conduction
2. conservation of energy
3. convection
4. fluid
5. heat
6. heat transfer
7. internal energy
8. mass-energy equivalence
9. mechanical equivalent of heat
10. radiation
11. thermal equilibrium
12. work

3.1 The Law of Conservation of Energy

In our energy study last chapter, we saw many examples of energy in one form being converted into another form. Nuclear energy produced by fusion reactions in the sun produces electromagnetic radiation. The gravitational potential energy in dammed-up water turns into kinetic energy as the water falls, and then electrical energy as the water spins a turbine-generator. Chemical potential energy in the molecules of fuel is converted into thermal energy in steam, and then kinetic energy in a spinning steam turbine, and finally into electrical energy by a generator.

There are dozens of examples like this of energy in one form being transformed into another. It was during the 19th century that scientists began to solidify the theory known as the *mechanical equivalent of heat*. According to this theory, mechanical forms of energy (such as kinetic energy) and heat are the same thing—energy. One can be converted into the other, but they are simply different forms of the same thing. At the time, this was a big discovery because for centuries scientists thought that heat was some kind of weightless gas—called *caloric*—that passed from warmer substances to cooler ones.

As usual in scientific research, many experiments exploring this issue were conducted by many scientists, but over time the caloric theory just didn't hold up. Heat was not a substance or gas flowing out of hot objects. Later in this chapter, we will explore the nature of heat in more detail—how energy is stored inside substances, and how it is transferred from one substance to another. For now all we need to note is that heat is just a form of energy, like kinetic energy and the other forms of energy we have studied.

Once the experimentation of the 18th and 19th centuries had made evident the principle of the mechanical equivalent of heat, scientists soon discovered the *law of conservation of energy*, one of the most fundamental laws in physics. This important law is stated in the following box.

The law of conservation of energy:

Energy can be neither created nor destroyed, only changed in form.

To illustrate this principle, let's look at two examples. The first example is a kid sliding down a metal slide, as depicted in Figure 3.1. At the top of the slide, the kid is at rest. His body has gravitational potential energy because of his elevated position in the gravitational field of the earth. As he slides down, the gravitational potential energy converts into kinetic energy as the kid picks up speed. Also, the friction between the kid's pants and the slide causes heating, and heat is released into the atmosphere. This is because friction on moving objects always causes heating, which always releases energy into the environment. When he reaches the bottom, he has no gravitational potential energy left. The energy he started with has all been converted into heat and kinetic energy.

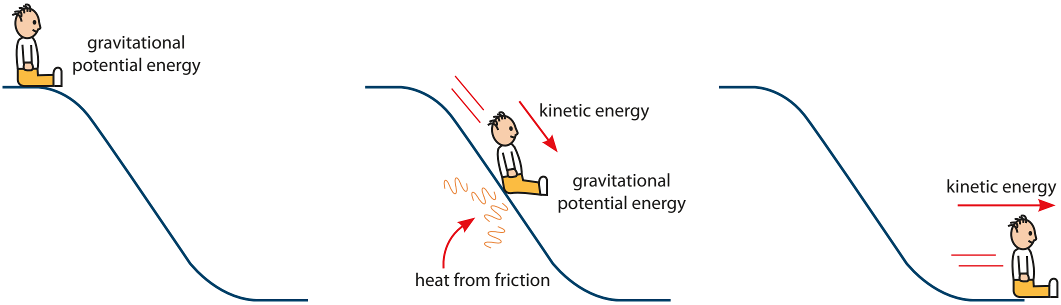


Figure 3.1. Energy transformations as a kid slides down a slide.

According to the law of conservation of energy, none of the original gravitational potential energy is lost or destroyed, and no new energy is created. The only thing that happens is that the gravitational potential energy the kid starts with converts into different forms of energy. We can even express this in the form of an equation, like this:

original gravitational potential energy = final kinetic energy + heat produced by friction

This is a sort of accounting equation. It states the kind of energy we start with and then accounts for where it all goes. The equation says that all the gravitational potential energy the kid has at the beginning is equal to the sum of the kinetic energy he has at the end and the energy released as heat on the way down.

Our second example is to track the energy involved in an exploding firecracker, as illustrated in Figure 3.2. Before the explosion, there is chemical potential energy in the chemicals in the firecracker. With the explosion, this chemical potential energy is converted into several different forms of energy, including energy in the light, heat, and sound from the explosion, as well as the kinetic energy in the flying debris as the firecracker blows apart.

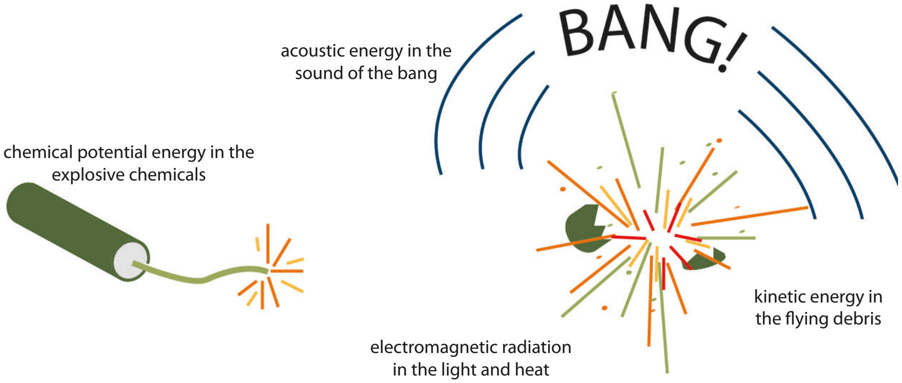


Figure 3.2. Energy transformations in an exploding firecracker.

As in the previous example, when the firecracker explodes no energy is created or destroyed. The original energy is all there, just in different forms. Writing this in an equation,

original chemical potential energy = kinetic energy in flying debris + heat and light + acoustic energy

With one exception, which we examine in the next section, current scientific theory now holds that the law of conservation of energy applies to every process and in every part of the universe. It is one of the fundamental laws of physics. In the next section, we take the law of conservation of energy one step further.

Learning Check 3.1

1. What is "caloric"?
2. State the law of conservation of energy.
3. Make up three of your own examples, different from the ones in the text, that demonstrate the law of conservation of energy.
4. When friction is present on a moving object, how does this affect the amount and forms of energy present in a given situation?

3.2 Mass-Energy Equivalence

From the previous chapter, you know that it was Albert Einstein that first theorized that light and energy are quantized. In 1905, when he published his famous paper on the subject, Einstein also published a paper demonstrating that mass and energy are related—equivalent, in fact—and that one can be transformed into the other! This theory is now called *mass-energy equivalence*.

The equation Einstein discovered is one of the most famous equations in the history of science:

$$E = mc^2$$

In this equation, E stands for energy, m stands for mass, and c stands for the speed of light, which is 300,000,000 meters per second. The equation basically says that there is an equivalent amount of energy associated with any given amount of mass. If you take a certain mass, in kilograms, and multiply it by the square of the speed of light (a very large number), the result is the equivalent amount of energy associated with that amount of mass.

Mass and energy are related, and one can be converted into the other.

Remember our discussions about fission and fusion in Chapters 1 and 2? In each case, energy is released. Einstein's equation enables us to understand why. When two protons fuse together during fusion, their mass after they stick together is a tiny bit less than the sum of the masses of the two protons before they fuse together. What happens to the rest of the mass? It is transformed into energy, just as Einstein's equation predicts. The same thing happens in fission. After a large atomic nucleus has been split apart, the sum of the masses of all the pieces is less than the original nuclear mass. The difference is converted to energy. This is truly amazing. It is also amazing that Einstein formulated this theory long before any experiments could be performed to confirm it.

So far as we know, the only exception to the law of conservation of energy presented in the previous section is when mass is converted to energy during a nuclear reaction. But if we take the mass-energy equivalence into account using Einstein's equation, then the law of conservation of energy applies across the board, without exception. Scientists refer to this as the *conservation of mass-energy*.

Learning Check 3.2

1. Where does the energy come from in the fission reactors we use to produce electricity?
2. What does *mass-energy equivalence* mean?

3.3 Heat and Heat Transfer

In the context of science, *heat* is a technical term with a very specific meaning. The term heat applies specifically to energy that is in the process of being transferred from a warm object to a cooler one. In fact, it is incorrect to refer to an object or substance as containing or possessing heat. You can say that an object has kinetic energy, and you can refer to the internal energy of a substance (which I explain later in the chapter), but heat is a term that refers to energy that is in transit—on its way from one place to someplace else. In this section, we look at the three ways this happens.

No doubt you already know that heat always flows from hotter objects to cooler objects. (We are not going to talk about thermodynamics much in this course, but in case you are wondering, it is the second law of thermodynamics that says heat always flows from the warmer object to the cooler one and never the other way around.) Heat continues to flow from the warmer object to the cooler one until they reach the same temperature. When they are the same temperature and heat flow between them ceases, the objects are in a state called *thermal equilibrium*.

Objects are in thermal equilibrium when they are at the same temperature, and no heat is flowing between them.

There are three ways heat can transfer from one substance to another. First, we have already seen (Section 2.3) how heat can travel as electromagnetic waves. Both the light and heat from the sun travel to earth as electromagnetic radiation. When we refer to heat transfer by *radiation*, this is what we mean.

We can see light, of course, but we cannot see the heat from a hot object like the sun because heat is in the infrared region of the electromagnetic spectrum. In Figure 3.3 is a sketch I drew to suggest how heat can radiate from a hot object, such as a horseshoe being heated in a blacksmith's forge. The red wavy lines are supposed to suggest the heat radiating from that hot horseshoe, but as I said, we cannot see the heat. We sure can feel it on our skin, though!

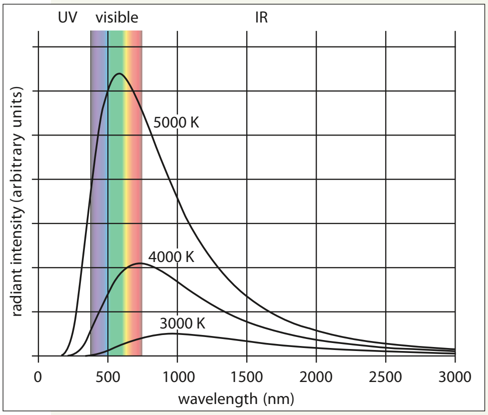
Heat transfer by radiation occurs when energy moves by infrared electromagnetic waves.

The second way heat transfer happens is by a process called *conduction*. Conduction occurs in solids, and of all solids metals conduct heat the most readily.

As with radiation, conduction is a very familiar process to all of us. You know that if you put a metal object, such as an iron frying pan, on a fire the handle of the object soon gets hot.

Scientists, Experiments, and Technology

All warm objects emit infrared radiation into the environment. In fact, by detecting the wavelength where the strongest radiation is, we can calculate the temperature of the object. This is because at any temperature, a warm object radiates a range of wavelengths, and the radiation is strongest at a particular wavelength for a given temperature. The hotter an object is, the shorter the wavelength of the peak in the radiation the object emits.



In the graph shown to the left, the black curves show the radiation emitted by a hot object at three different temperatures. The 5000 K curve is at about the surface temperature of the sun. The 3000 K curve is a bit below the temperature of the glowing metal filament in a traditional light bulb. Note that the peak in the curves moves to longer—more infrared—wavelengths as the temperature gets lower.

In the images below, the upper photo was made with visible light. The lower photo was made with infrared light, and then the different infrared wavelengths were translated to visible wavelengths so we can see the radiation patterns. The temperature scale in the lower photo associates the colors in the infrared photo to the temperature.

Notice that the black bag is opaque to visible light, but transparent to infrared. The reverse is true of the man's glasses. The color of the bag indicates that it is nice and cool—about 75°F. Notice also that the man's facial hair is the same temperature as his face, so it appears as the same color in the infrared photo.

The relationship between the surface temperature of an object and the radiation it emits gave birth to a great new temperature measurement technology a few years ago. The hand-held device uses a lens to capture the infrared radiation from an object and display the object's surface temperature.

These devices have built-in laser pointers to make it easy to point the device at a distant object, but the laser is not part of the temperature sensing at all. In the photo to the left, a maintenance employee is measuring the temperature of the walls in a building to help assess how the building's air conditioners are performing. You can see the laser spot on the wall in the background.

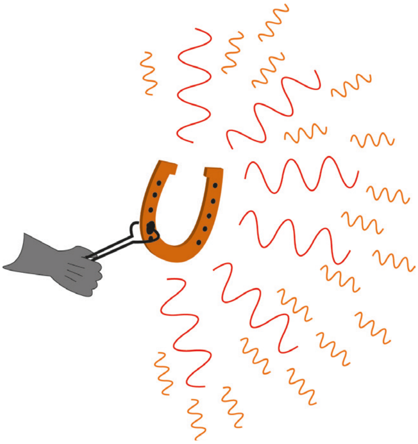


Figure 3.3. Heat transfer by radiation.

This happens even if the handle isn't over the fire. The reason is that when an object gets hot, the atoms inside the object vibrate very vigorously. In a metal, these atomic vibrations in the hot part of the object are transferred to other nearby atoms so that they begin vibrating vigorously, too, which means they are hot, too. The sketch in Figure 3.4 illustrates this process.

In the sketch, the blue spheres represent the atoms in the metal. I drew them in a regular, geometric pattern because in metals that's how the atoms are arranged. Underneath the metal, there is a heat source, such as a gas flame on a stove. As the heat from the flame warms the atoms in the metal, they begin vibrating much faster. These vibrations are transferred to neighboring atoms, which warms them so they begin vibrating faster, too. By this process of transferring vibrations, the heat spreads throughout the solid metal, although the atoms near the flame are always vibrating the most vigorously, and so are the hottest.

The third way heat transfer can occur is by *convection*. Convection occurs in *fluids* (liquids and gases). In fluids, atoms are free to move around, mix and mingle, and bump into each other. In hot fluids, the atoms are moving faster and in cool fluids the atoms are moving slower. As illustrated in Figure 3.5, if a hot fluid mingles with a cool fluid, the hot, fast atoms begin colliding with the cooler, slower atoms.

Heat transfer by conduction occurs when vibrating atoms in solids cause nearby atoms to vibrate, too.

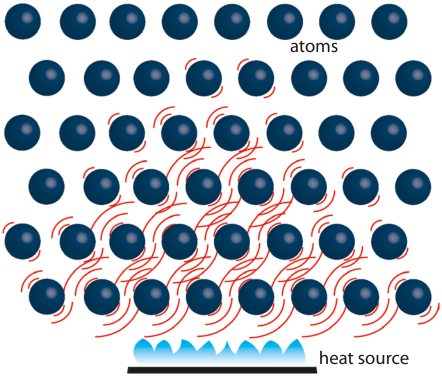


Figure 3.4. Heat transfer by conduction.

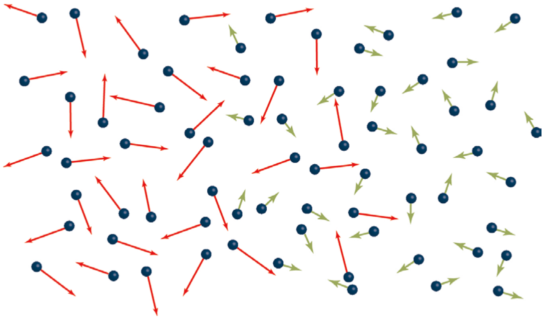


Figure 3.5. Heat transfer by convection. Red arrows represent fast, hot particles. Green arrows represent slower, cooler particles.

This mingling causes the hot atoms to transfer some of their kinetic energy to the cooler atoms. In the end, the cooler atoms have been warmed up by having energy transferred to them from the hot atoms.

A good example of convection at work is in the old radiators commonly used to heat homes in the days before central heating systems (and still in use in many older homes, particularly in the northern U.S.). Hot water is pumped through the inside of the radiator, making the iron radiator warm to the touch. When air molecules collide with the hot surface, they pick up kinetic energy from the rapidly vibrating atoms in the metal. These hot, fast moving molecules then gradually work their way through the room, colliding with the slower, cooler molecules and exchanging energy so the cooler molecules begin moving faster, which means they get hotter.

Heat transfer by convection occurs when hot and cold particles in a fluid mix and collide, causing slower, cooler molecules to gain kinetic energy and speed up.

Learning Check 3.3

1. Why is it incorrect to say that an object has heat in it?
2. What is thermal equilibrium?
3. How does conduction work?
4. How does convection work?
5. Write a paragraph explaining how we can determine the surface temperature of an object by sensing the infrared radiation the object is emitting.

3.4 Work

In the previous section, you learned that the term heat describes a process in which energy is transferred from one object to another. The term *work* is used to denote another such process. Work, like heat, is a technical term with a very specific meaning. Work is a *mechanical* process of transferring energy from one machine or person to another. When work is performed, a force is applied to an object, and the object is moved a certain distance in the direction of the force. This process always results in energy transfer.

Figure 3.6 shows four examples of work being performed. First, when an archer stretches back a bowstring, he does work on the bow. This results in potential energy stored in the bent bow. When the archer releases the bow, the bow does work on the arrow by pushing the arrow very hard for a few inches. The result of this work is that the arrow gains kinetic energy. In the second example, in the upper right, some boys are pushing a car up a hill. We say that the boys are *doing work* on the car. The result is that the car now has gravitational potential energy, since it is at the top of the hill. In the third photo, a white car is giving a push start to a red race car. The race car was at rest, and now is moving, so the white car did work on the red car, and the red car now has kinetic energy. Finally, a construction crane hoists

Figure 3.6. Four examples of work, in which energy is transferred from one machine or person to another by applying a force and moving a distance.

a bucket of concrete up in the air. The crane does work on the bucket, and now the bucket has gravitational potential energy.

When work is performed, an applied force causes an object to move in the same direction.

There is one more thing to notice about work. When work is done, energy transfer occurs. For this to happen, the force doing the work and the distance involved must point *in the same direction* or along the same line. If they are at right angles to one another, no work is done.

This is illustrated in Figure 3.7. When lifting a bucket, a person does work on the bucket. Energy is transferred in this process because some of the energy in the person's body (chemical potential energy) is transferred to the bucket, which now has gravitational potential energy. But during the process of carrying the bucket from one place to another, *no work is done on the bucket*. The bucket is not being raised, so it is not gaining gravitational potential energy. And it is not being accelerated, so it is not gaining kinetic energy (except a little nudge at first to get it going, but that is not what I am talking about here). The bucket is not gaining any energy because the upward force applied to hold up the bucket is at right angles to the distance the bucket is being moved.

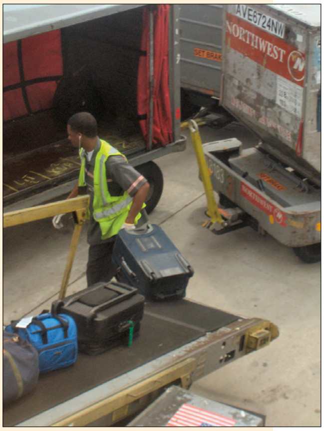
Figure 3.7. In raising the bucket (left), work is done on the bucket. In moving the bucket horizontally, no work is done on the bucket.

In this second case, does the person do any work at all? Yes, *but not on the bucket*. To perform the task of carrying the bucket, the energy transfer is heat from the person's body into the air. (This is a very complex process, and we cannot say what the work is done *on* without getting into the biology of the human body, which we are not going to do.) In short, since the bucket gains no energy, no work is done on it.

Learning Check 3.4

1. Make up four examples of your own that illustrate one machine or person doing work on another.
2. If you press as hard as you can against a brick wall until you begin breathing hard and sweating, did you do any work on the wall? Explain your answer.

3. In the photo to the left, food items are slowly moving along on a conveyor belt. Is the conveyor belt doing work on the food? Explain your answer.
4. At the right, baggage is moving up a conveyor belt into an airplane. The conveyer loads the baggage on the ground, and transports it up into the airplane. Is the conveyor belt doing work on the baggage? Explain your answer.



3.5 Internal Energy

When describing convection in Section 3.3, I noted that the particles in a hot fluid are moving faster than the particles in a cooler fluid. The fact that hotter particles move faster than cooler particles is very significant, and relates fundamentally to the energy in a substance.

Every substance is made of atoms, and the atoms of every substance are always in motion. In a solid, the atoms vibrate. In a fluid, the atoms are moving around at high speed. This means the atoms in any substance always have kinetic energy. This kinetic energy in the atoms in a substance enables a substance to absorb energy by being heated. The hotter the substance is, the faster its atoms move and the more kinetic energy the atoms have.

The *internal energy* of a substance is the sum of all of the kinetic energies of the individual particles (atoms or molecules) in the substance. Now, even though the number of particles in any ordinary quantity of matter is colossal, scientists have mathematical techniques that allow them to compute this sum, and thus to determine the internal energy in a substance. The hotter a substance is, the faster its particles are moving and the higher its internal energy is.

Internal energy is the sum of all the kinetic energies of the particles in a substance.

Now that you know about internal energy, let's consider the entire picture about the energy in an object as it warms up, how the energy is stored in the object, how the energy is transferred into and out of the object, and so on. Figure 3.8 is a photograph of one side of a hollow brick wall, with bricks on one side of the wall warming in the sun. The other side of these bricks is the inside of the wall, where it stays cool and dark. Let's use these warming bricks to consider how heat flows through the wall. Refer to the diagram in Figure 3.9 as we go.

Figure 3.8. Bricks in the sun on a warm day.

First, the energy warming these bricks is in the infrared electromagnetic radiation arriving at the bricks from the sun. You might think that some of the energy warming the bricks would be from convection in the heated air, as the hot air molecules hit the bricks and transfer kinetic energy to the atoms in the bricks. But bricks in the direct sun become much hotter than the surrounding air, don't they? This means that the bricks are actually warming the air, rather than the other way around. On the left of the diagram, the electromagnetic radiation from the sun is shown arriving at the outer surface of the bricks.

Okay, so the energy in the infrared electromagnetic waves is absorbed by the atoms on the bricks' surface, increasing their thermal energy. What does this mean the atoms do? They vibrate faster—because the radiant heat has been transferred to the atoms in the bricks. Since they are very hot now, they are vibrating vigorously. Then, since the bricks are solid, the atoms in the next layer of brick begin vibrating faster, too, and so on, one layer after another, as the energy works its way by conduction to the inside of the brick. The heat conducts its way to the cool side of the bricks, on the inside of the wall. Now, since the bricks are warmer than the cool air inside the wall, electromagnetic energy radiates from the bricks into the inside of the wall, warming it up a bit. I drew the waves inside the wall shorter (vertically) than the waves hitting the bricks from the sun to show that the heat ra-

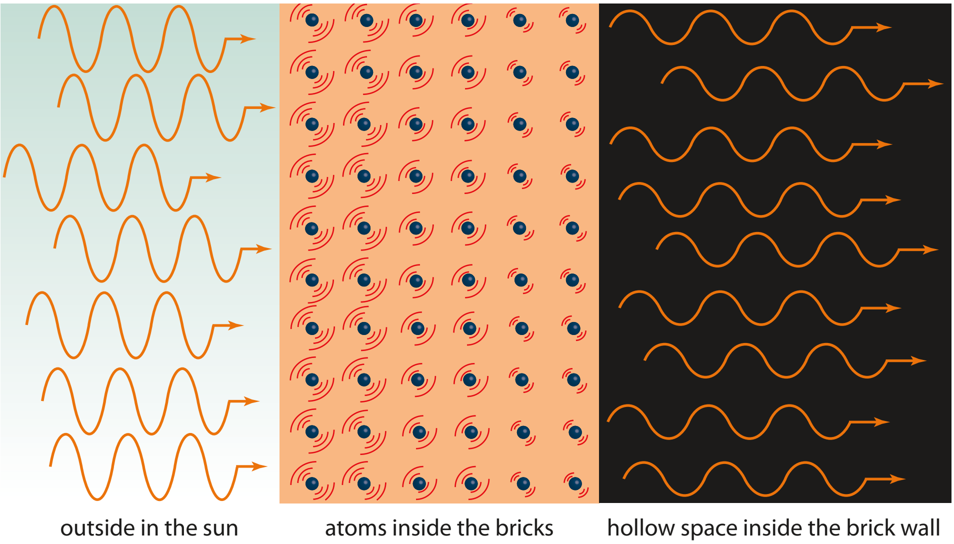


Figure 3.9. Energy transfer through a hollow brick wall. Energy arrives at the bricks, passes through the bricks by conduction, and radiates out the cooler side. (Note: Since the bricks are hotter than the surrounding air, some energy also radiates from the bricks to the left, back out into the air.)

diating inside the wall is less intense. I also made the waves radiating inside the wall to have longer wavelengths than those arriving outside. The reason for this should be clear from our study of electromagnetic radiation earlier in this chapter (see the box on page 50). Lower temperature means longer wavelength radiation.

As we end this section, there is one final point I wish to make about internal energy. If you are thinking that internal energy sounds a lot like the thermal energy we studied in Chapter 2, you are right. The two are very similar and some books treat them as synonyms. The energy in a substance from being heated, which is our definition for thermal energy, is simply the increase in the substance's internal energy that occurs from the heating.

But there is more than one way to increase the internal energy of a substance, so some authorities make this distinction between thermal energy and internal energy: the term internal energy refers specifically to the sum of all the kinetic energies in the particles of a substance. The internal energy can be increased two ways: by heating or by compressing the substance into a smaller volume. By contrast, the term thermal energy refers specifically to the portion of the internal energy that is due to heating.

Learning Check 3.5

1. Imagine an unopened can of your favorite soft drink sitting in the sun. Explain what is meant when referring to the internal energy of the liquid inside that can.
2. Think about your can of soft drink again as it sits in the sun. Explain how the liquid in the can gets hot. Don't be vague; use the terms and concepts we have encountered in the last two sections.
3. Think again about the brick wall we discussed in this section. Consider what changes in Figure 3.9 if the sun is suddenly covered up by a thick black storm cloud. Redraw the diagram, and explain what is going on in this new situation.
4. Building on the previous question and your new diagram, assume the sun never comes back out before nightfall. How long does the situation in your new diagram continue? What if it stays cloudy the next day and the overnight temperature holds steady with no sun for many days. What happens?

3.6 Summary: Where Is the Energy?

In this chapter and the last, we have covered the basics about energy. Now, based on what I have presented, if you think about it, there are really only a few basic ways that energy can be present in substances or in space. Just by way of reviewing and summarizing our study of energy, let's review these possibilities.

The first is in the random motion of the atoms in a substance. If it is a solid, they are vibrating. If it is a liquid or a gas, they are flying around (kinetic energy). The

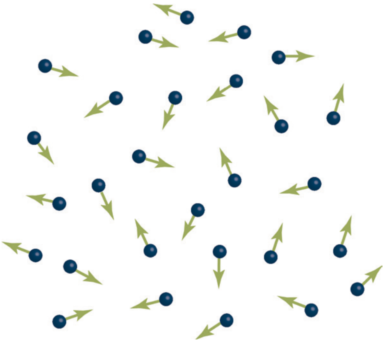


Figure 3.10. Internal energy: The sum of the kinetic energies of the moving particles.

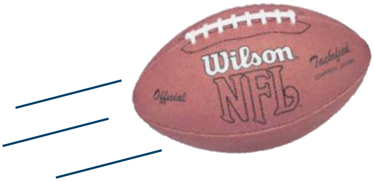


Figure 3.11. Kinetic energy (large scale): Energy in the overall motion of an object.

sum of all these kinetic energies is the substance's internal energy. The internal energy of a substance depends on its temperature. The hotter it is, the faster its particles move, and the higher its internal energy is. The internal energy of a gas is suggested by Figure 3.10.

The second way a substance can possess energy is if the substance as a whole is moving, so that as a whole it has kinetic energy. The substance could be moving in a line, rotating, orbiting or some combination of these. If so, the substance as a whole has kinetic energy. This is depicted in Figure 3.11.

The third way a substance can have energy is if the substance is in a field, so that it has potential energy. As suggested by Figure 3.12, we studied the gravitational potential energy present with objects in a gravitational field. The object could also be in some other kind of field, such as a magnetic field or an electric field. If so, then the object may have some kind of potential energy associated with that kind of field. Chemical potential energy is actually due to the energy in electrical fields around protons and electrons in substances. (We will look more closely at electric and magnetic fields later.)

Fourth, as Einstein discovered, there is energy associated with the mass in a substance, and during a nuclear reaction some of the mass in an atom is

Figure 3.12. Gravitational potential energy: The energy that will be released by objects in a gravitational field if they are no longer held apart.

Note: This is the famous and beautiful "Earthrise" photo taken by Apollo 8 astronaut Bill Anders. The moon is in the foreground. On Christmas Eve, during the mission, the Apollo 8 crew read the first 10 verses from the book of Genesis on a national television broadcast. At the time, that broadcast was the most-watched TV program ever.

converted directly into energy, as depicted in Figure 3.13. If we were able to tear apart the nuclei in the atoms of a substance, massive quantities of energy would be released. But the only way to get at *all* this energy would be literally to destroy the substance by tearing apart its very atoms and breaking them down into individual protons and neutrons.

Finally, energy is present in the electromagnetic radiation found throughout outer space. This includes the infrared, visible, and ultraviolet radiation coming from the sun and stars, as well as the Cosmic Microwave Background radiation.

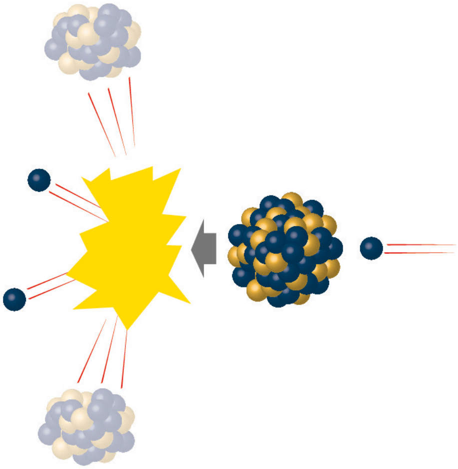


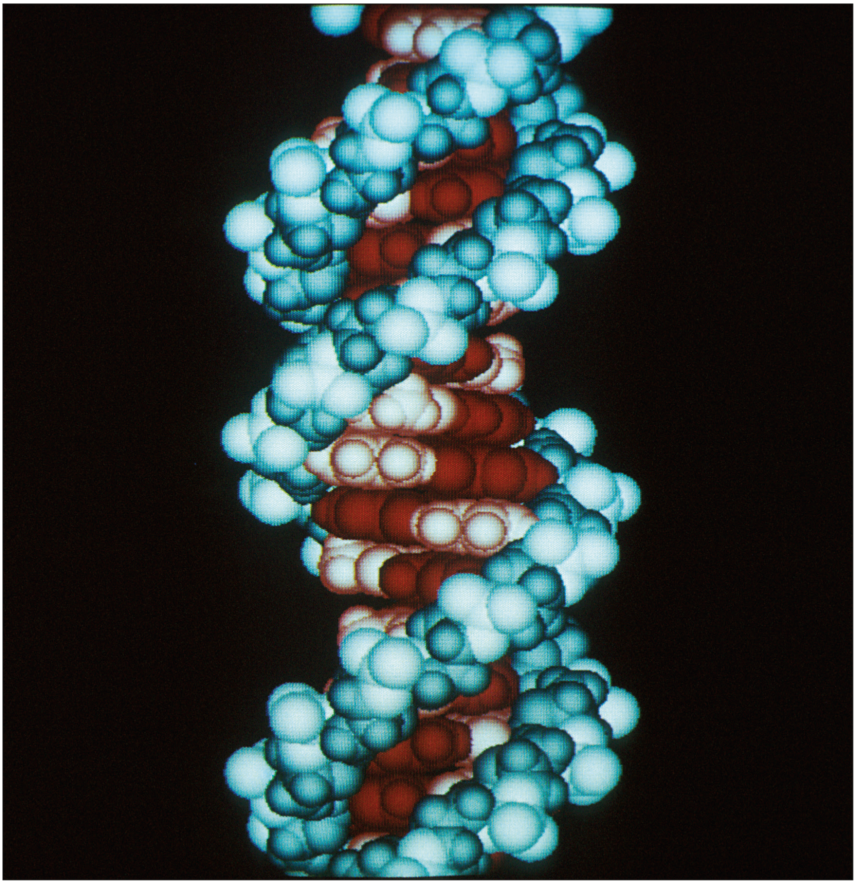
Figure 3.13. Nuclear energy: Some of an atom's mass is converted to energy during nuclear reactions.

Chapter 3 Exercises

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

1. Make up a situation in which you start with one form of energy, and some event occurs, causing the energy to be transformed into at least three other forms of energy. Use the law of conservation of energy to account for all the energy in your example.
2. Imagine you are camping, and you are sitting inside your tent in the sun on a hot day. Your tent is dark blue, so not much light comes in, and it is dark in there. Why does it get hot inside your tent? Explain how this happens.
3. Suppose there is a small gasoline engine in the top of a big warehouse. The engine is attached to some pulleys and is used to hoist cartons up to the second and third floors for storage. Explain how work is involved in getting a carton up to the third floor.
4. Consider again the previous question, and suppose you carry a gasoline can full of fuel up to the third floor and fill up the engine's gas tank. To do this, you must do work on the can of fuel. Does this work energy get converted into the gravitational potential energy of the cartons hoisted to the upper floors? Why or why not?
5. Consider a glass of ice water sitting in a windowless room in a house. The temperature in the room is 72°F. Describe how energy from the room finds its way into the ice cubes in the ice water to melt them.
6. Consider again the glass of ice water in the previous question. Does the idea of thermal equilibrium apply at all here? Explain your answer.

Chapter 4
Order and Design in Creation



DNA is an enormous molecule found in the cells of all living organisms. DNA is referred to as a macromolecule*, because it is assembled from groups of smaller molecules called sugars, phosphates, and nucleotides, all woven together in a spiraling shape known as a* double helix*. The chains of paired nucleotides in human DNA (shown in red in the image above) can be up to approximately 220 million pairs long. The sequencing of the molecules in DNA contains a sophisticated multi-layered code. Embedded in this code is the genetic information that specifies and governs the biological functioning and physical traits of the organism.*

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. Describe examples that illustrate the existence of "laws of nature."
2. Describe three possible explanations for why laws of nature exist.
3. Give examples of mathematical structure in nature, and explain why the existence of mathematical structure strongly implies that the universe was created by an intelligent designer.
4. Describe at least eight remarkable features of the universe, the galaxy, the solar system, or earth that suggest the earth was created with creatures like us in mind.
5. Put together a basic argument, based on scientific evidence, that belief in God makes a lot of sense.

VOCABULARY TERMS

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

1. atmosphere
2. Big Bang
3. faith-science debate
4. fine-tuning
5. galaxy
6. laws of nature
7. magnetosphere
8. Milky Way
9. solar system
10. solar wind
11. steady-state universe

4.1 Why Are There Laws of Nature?

It is so common to hear people refer to the "laws of nature" that this phrase usually goes by without a second thought. But if you stop and think about it, the fact that laws of nature exist is actually quite remarkable. According to the standard scientific description of the origin of the universe, the entire universe began with an inconceivable explosion of energy, an event known as the *Big Bang*. From the moment the Big Bang happened, the laws of physics were present to shape the emerging matter and energy over 13.8 billion years into the stars, galaxies, and solar systems we see today. How could it be that from such an explosion a set of unwritten, mathematical principles would spontaneously emerge, and that these principles would consistently govern the behavior of matter and energy forever after?

Let's think about this for a moment. You know what explosions are like; you've probably seen thousands of them in movies. They are massively chaotic, with material flying everywhere and light and heat radiating out from the center of the explosion. But even in the midst of the chaos of an explosion, like the one shown in Figure 4.1, the motion of all the fragments, the patterns of light and heat, and the new compounds formed by the chemical (or nuclear) reactions involved are all governed by the laws of physics and chemistry. And apparently these laws were there from the beginning of the universe, governing the expansion of electromagnetic radiation from the moment of the Big Bang, the moment when the divine Creator spoke the creation into existence.

Figure 4.1. Even the chaos of explosions is governed by the laws of physics and chemistry.

What do we mean by the "laws of nature"? Well, in the most general sense this phrase refers to everything in the entire domain of science, from the laws of electricity and magnetism, to the chemistry of exploding gunpowder, to the chemical system of detection and communication ants use to swarm a lump of sugar, to the patterns of behavior exhibited by a hunting tiger. The plain fact is, there *are* laws that govern how nature works. If there weren't, the matter and energy spewing out from the Big Bang would have had no plan or program for what to do next, and there would have been no regulating principles to bring order to the expanding mess. It would be just a mess of stuff, nothing else.

Consider also that in order for us to do science at all, there must be predictable laws governing the way nature works. Without predictable laws, nature would not submit itself to scientific analysis. But if that were the case, we wouldn't be here to analyze it because the existence of life itself depends on predictable, orderly laws governing the way matter and energy interact.

Science depends on the regular behavior of the world around us. If there weren't laws of nature, there would be no science. There would be no people, either.

The title of this section is, "Why Are There Laws of Nature?" There are only really three ways to formulate an answer this question. The first would be to say that there is no reason. It just happened that way by chance and without logic, thought, or purpose. The second answer is to say that there is some underlying natural principle, that just happens to be part of nature, and compels things to be this way. We have no idea what this principle could be, or how it could even be there.

The third way to answer the question is to say this: the order and structure in nature is so complex and finely balanced, the only way to make sense of what we see is to acknowledge that the universe was *intentionally and intelligently designed*. This finely-tuned universe was "Built for us," as Nicolaus Copernicus wrote, "by the Best and Most Orderly Workman of All." This third answer is, of course, the testimony of the Bible, which opens with the supremely memorable and authoritative statement, "In the beginning God created the heavens and the earth." For those who have eyes to see it, the hand of God is the only believable explanation for the existence of the physical and chemical laws that govern the universe. But to support the Bible's claim, let's take a closer look at the order and structure we find in nature.

Learning Check 4.1

1. What is meant by the phrase "laws of nature"?
2. What are some examples of evidence for the existence of laws of nature?
3. Describe three possible explanations for why laws of nature exist.

4.2 Order and Structure in Nature

It has been said that all the basic laws of physics that govern the physical behavior of the known universe—which are expressible in mathematical equations—can be written on a single sheet of paper. Isn't that astonishing? Here are a few examples of these laws. In Figure 4.2 are the famous "Maxwell's Equations." These four equations were published by Scottish physicist James Clerk Maxwell in 1864, and they describe all of classical electricity and magnetism, including radio waves and light.

$$\nabla \cdot D = \rho_f$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = J_f + \frac{\partial D}{\partial t}$$

Figure 4.2. Maxwell's equations describe all electricity and magnetism.

Everything we know about gravity is summarized in the general theory of relativity, shown in Figure 4.3. German physicist Albert Einstein published this theory in 1916. Maxwell's equations are difficult to learn and understand, but they are nothing compared to the difficulty of the mathematics behind this equation of Einstein's. And yet the main operating principle of all the gravity in the universe can be expressed in a single equation!

The behavior of particles such as protons and electrons at the atomic or quantum level is summarized by the "Schrödinger equation," shown in Figure 4.4. This equation, published in 1926 by Austrian physicist Erwin Schrödinger, has dominated physics in the 20th and 21st centuries (along with Einstein's equation).

$$R_{ab} - \frac{1}{2} R g_{ab} = \frac{8\pi G}{c^4} T_{ab}$$

Figure 4.3. The primary equation of Einstein's general theory of relativity, a geometrical description of space and time that accounts for gravity.

$$i\hbar \frac{\partial}{\partial t} \Psi = \hat{H} \Psi$$

Figure 4.4. The general Schrödinger equation, describing the behavior of systems at the quantum (atomic) level.

$$\sigma_x \sigma_p \geq \frac{\hbar}{2}$$

Figure 4.5. An expression of the Heisenberg uncertainty principle, describing limits on what observers like us can know about objects at the quantum level.

And the limits on what it is possible to know about any quantum system are summarized by the Heisenberg uncertainty principle, shown in Figure 4.5.

Of course, there are a few thousand other equations that come up in the study of physics, but it is amazing that they really all boil down to those shown here and a few others. The breathtaking complexity of the matter and energy we see in creation can be summarized so simply and elegantly! Not only that, but we can discover these laws and understand them! It is not at all obvious that the universe—and the powers of the human mind—should be this way.

Now, just as amazing as the simplicity and comprehensibility of nature's mathematical structure is the fact that nature has any mathematical structure at all. Why should the laws of nature be *mathematical*? Mathematics involves logic and coherent, consistently applied rules. Where could this logic have come from? It is impossible to imagine the existence of mathematical structures in nature without an intelligent, logical mind behind their existence. Many scientists have wondered about this. Several have written comments such as this statement by a Nobel Prize winning physicist: "the miracle of appropriateness of the language of mathematics for the formulation of the laws of physics" is "something bordering on the mysterious."

Many scientists have agreed that the mathematical structure of nature is a mystery that seems miraculous.

If the universe got here without planning, then why doesn't it *look* random and haphazard, the way randomly assembled piles of things usually do? How could a completely random and mindless universe exhibit such profound *mathematical structure*? The short answer to this question is that it couldn't.

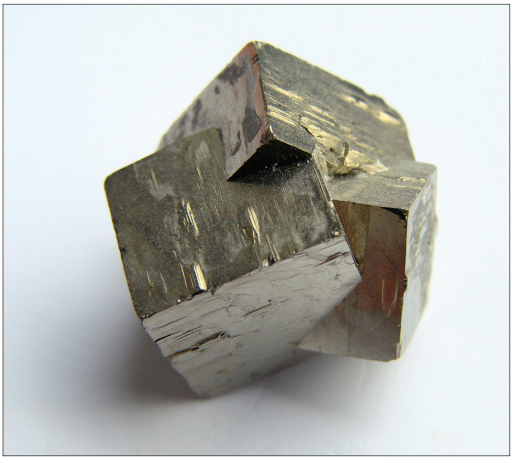


Figure 4.6. Pyrite crystals exhibiting an effect known as "twinning."

I have shown you some of the equations in physics that illustrate the order and structure embedded in nature. Now I want to show you some beautiful examples how this mathematical structure is evident just by *looking* at nature.

Just check out the stunning, three-dimensional arrangement of cubes in the pyrite crystal of Figure 4.6. This is not just mathematical; it looks like someone has been *playing* with mathematics!

Now, we all know about the planets in our solar system. The very creative image in Figure 4.7 shows them to scale, next to one another for size comparison (and for just gazing at their beauty.) Thousands of astronomers have labored at working out the mathematics of the planetary move-

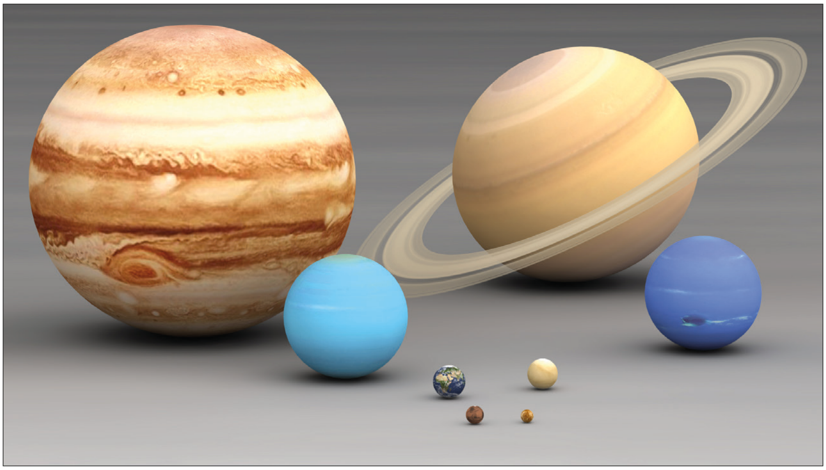


Figure 4.7. The beautiful planets (left to right, back to front): Jupiter, Saturn, Uranus, Neptune, Earth, Venus, Mars, and Mercury.

ments. All the planets travel in elegant, predictable orbits around the sun, and their orbits are all *elliptical*, which means they are shaped like this ⬭, and can be characterized with equations that look like $ax^2 + by^2 = 1$. All the planetary moons travel in ellipses around their companion planets as well. (Some cool asides: the famous Great Red Spot on Jupiter is about three times the size of the earth. It is a giant storm, and we have known about it here on earth for 350 years. Saturn's rings are made almost entirely of water ice, and average about 20 meters thick. The outer diameter of the rings is about the same as the distance from earth to earth's moon.)

Now let's talk about the fruit fly, commonly used in biology classes all over the world to study the *mathematical* laws of genetic inheritance (which we won't go into). It is such a simple little bug, common and easily squished. But check out the magnificent geometry built into the eye of a fruit fly shown in Figure 4.8, an image captured by a scanning electron microscope (SEM). Figure 4.9 is another image of an eye captured by an SEM, the eye of an antarctic krill. (Krill are small ocean

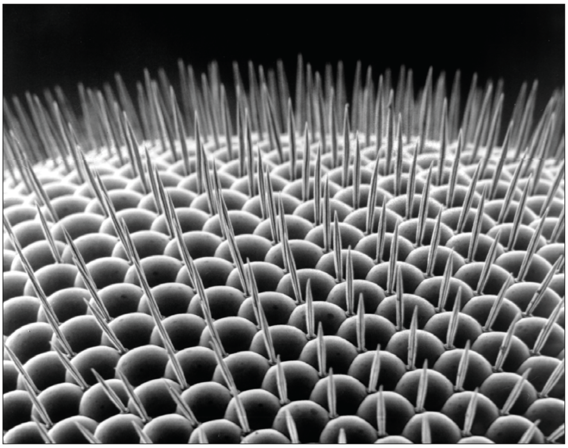


Figure 4.8. A scanning electron microscope image of the eye of a fruit fly.

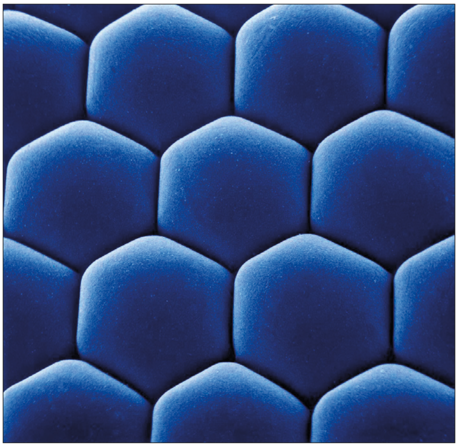


Figure 4.9. A scanning electron microscope image of the eye of an antarctic krill.

crustaceans related to shrimp, with bodies about 3/4 inch long.) Perfect hexagons—imagine that!

We could go on endlessly with these examples, but let's look at just two more beauties. Figure 4.10 shows another SEM image, this time of a single-celled member of the algae family. If you can believe it, this thing is only about 10 micrometers in diameter, which is only about 20 times the wavelength of visible light. I just can't get over the rich, velvety beauty of this image. And mathematical structure? This thing looks like it was built in a watch factory! (By the way, scientists don't yet know what those round things are for. But I am confident they are there for some reason, even if it is just to amaze us.)

Figure 4.10. A scanning electron microscope image of a coccolithophore, a single-celled algae that is abundant in the oceans.

Figure 4.11. This bobtail squid is only a few centimeters long, but its light emitting capabilities allow it to hide its own silhouette.

Finally, in Figure 4.11 we have one of the world's cutest marine animals, the bobtail squid! (I'm sure you will love this: they are also known as dumpling squid, or stubby squid.) This little guy is only a couple of inches long. Don't you love the spiraling pattern of colors? (Why do the colors *spiral*?) But listen to what this critter has going on: it can create its own "invisibility cloak." No, really. This squid has a mantle called the "light organ," which is home to a glow-in-the-dark species of bacteria that live underneath it. By means of a fantastic optical system composed of a color filter, lens, and reflector built-in to the squid's mantle, the bacteria emit light beneath the animal. From below, this light mimics the appearance of the light hitting the top of the squid. The net effect of this superb optical imaging system is to mask the squid's own silhouette and protect the squid from predators! Imagine a squid and some bacteria having such elegant control over electromagnetic radiation. (You might also be interested to know that in exchange for the lighting service, the squid feeds the bacteria on sugar and amino acids.)

Oh wait—I almost forgot about the Fibonacci sequence, found all over the place in pine cones, sunflowers, flower stems, honeybees, and nautilus shells. On second thought, I will leave this one for you to look up yourself.

Learning Check 4.2

1. Describe some equations scientists use to model the laws of nature.
2. Describe some examples in which the mathematical structure in nature is evident from its appearance.

4.3 Nature Was Designed with Us in Mind

For several decades now, scientists have been aware of quite a number of coincidences associated with the existence of complex life on planet earth. Ever since the early 1970s, a debate has been raging as to whether these coincidences mean (a) the universe was designed for us to be here, or (b) there are underlying principles we don't know about that guarantee things would be this way, or (c) things just happen to be as they are, and there is no reason for the way they are.

No matter what a person believes about these things, that belief is an act of faith. To believe that God created the universe is an act of faith, but to believe that there is no God and that everything got here by itself is equally an act of faith. It is common in our day for people to ridicule anyone who publicly affirms belief in God, and to regard believers as unenlightened, simple-minded or primitive. This is nothing new; Jesus said explicitly that his followers would endure persecution (John 15:20) such as this kind of ridicule.

There is a reason these matters always come up in scientific discussions. Science is about explaining how the physical world works. If it appears to some people that everything can be explained without the need for belief in God, then scoffers feel like they have the ammunition they need to mock those who believe. Again, this is nothing new. The Apostle Peter wrote that there would be scoffers who would question belief in God, saying, "Where is the promise of his coming? For ever since the fathers fell asleep, all things are continuing as they were from the beginning of creation" (2 Peter 3:4).

We cannot settle the debate here. But I would like to suggest to you a few things about the so-called *faith-science debate*. First, the world we live in is amazing. For us to be here a great number of conditions must be met. Clearly, all these conditions *have* been met, because we are here. Second, this means each of us must respond to this situation somehow. Studying and understanding these things is worth your time and effort. It is common in our time for people to adopt the attitude that none of this matters, and that enjoying life is a lot more fun than endless debates about God. But it is God's desire that we are always "prepared to make a defense to anyone who asks you for the reason for the hope that is within you" (1 Peter 3:15).

So let's take a look at just a few of the many remarkable features associated with life on earth.