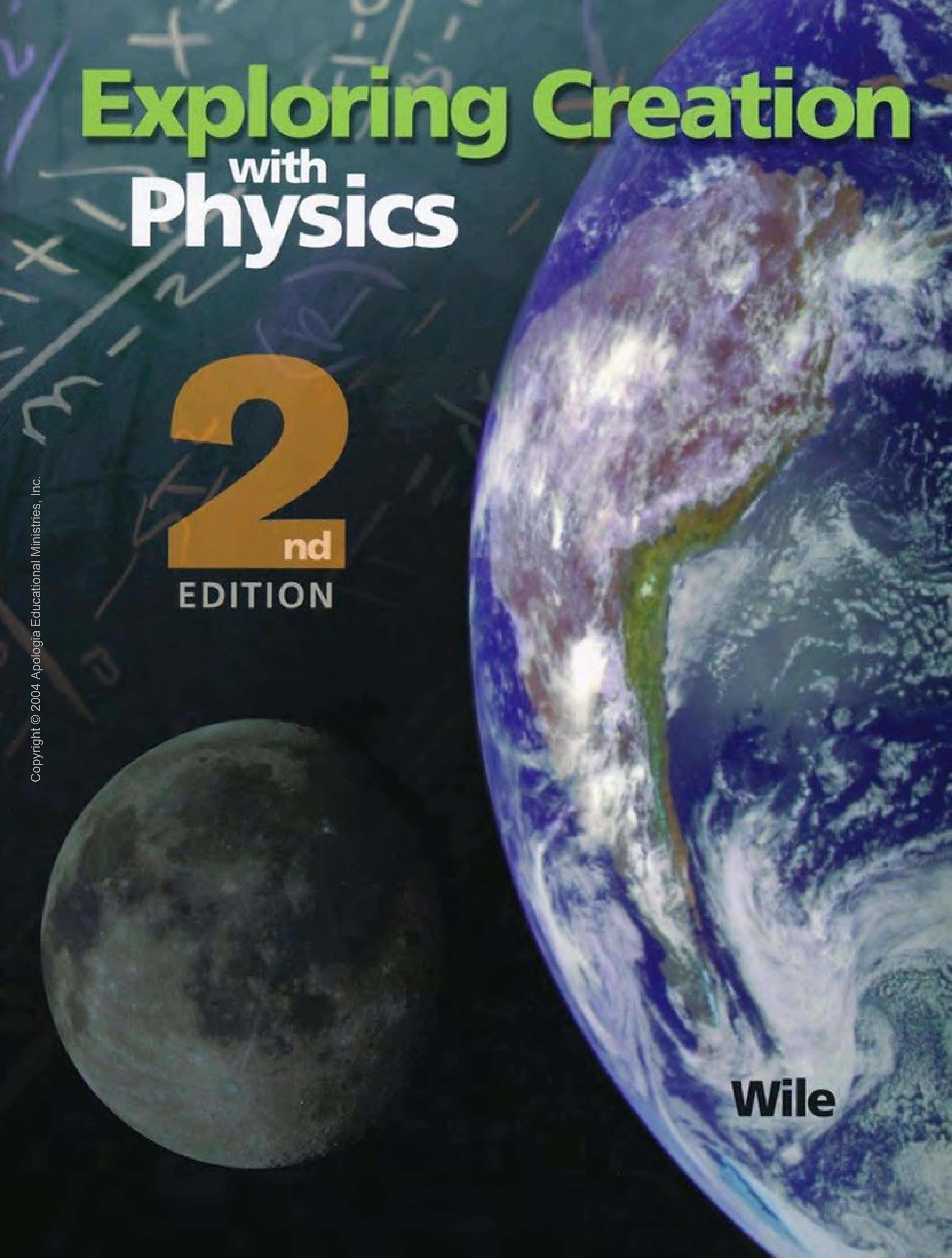
Exploring Creation with Physics

2nd EDITION



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Exploring Creation With Physics
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Introductory Remarks

In this course, you will study the science of physics, which is often referred to as the "fundamental science." Why is it called that? Well, as Ernest Rutherford (pictured below) once said, "All science is either physics or stamp collecting" (J. B. Birks, *Rutherford at Manchester* [New York: W. A. Benjamin, 1962], 108). What he meant was quite simple. In principle, all fields of science can be reduced to physics. Since physics attempts to understand in detail how everything in the universe interacts with everything else, any phenomenon in nature is controlled by the laws of physics.

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Ernest Rutherford

Ernest Rutherford (1871-1937) was born in New Zealand and was educated at both the University of New Zealand and Cambridge University. He determined that there are three types of naturally-occurring radiation, and he named them "alpha," "beta," and "gamma." We now know that alpha particles are helium nuclei, beta particles are electrons, and gamma rays are high-energy photons (light). Rutherford is probably most famous for his experiments on the structure of the nucleus. By bombarding a gold foil with alpha particles and watching how the alpha particles were deflected by the foil, he concluded that the atom is composed of a dense, positively-charged nucleus around which electrons orbit. He was also the first to produce an artificial nuclear reaction. Rutherford was awarded the Nobel Prize in Chemistry in 1908.

If Rutherford's statement is true, why do we have other fields of science? Why doesn't everyone just study physics? Well, this is what the "stamp collecting" part of Rutherford's quote means. Even though the laws of physics apply to all fields of science, there are many, many aspects of nature that are simply too complex to explain in terms of physics. For example, even the simplest life form in the universe is incredibly complicated. A single-celled creature such as an amoeba has hundreds of thousands of processes that work together to keep it alive. It is simply too complicated to explain each of these processes and how they interact in detail. As a result, the science of biology simply collects all of the facts related to how an amoeba functions, much like a stamp collector collects stamps.

In other words, although the underlying principles which control all of the processes that occur in an amoeba obey the laws of physics, the specifics of how they function and interact are far too complex to understand in detail. As a result, the science of biology collects the facts that we know about an amoeba and tries to draw conclusions from those facts. If, at some point in the future, humankind has the ability to explain such complex systems in terms of physics, the science of biology may not be necessary, because physics may be able to explain everything regarding living systems. Thus, physics is called the fundamental science because it forms the basis of all other fields of science.

Of course, if you are going to attempt to study and understand the details of how things interact in nature, you will have to do a lot of observation and experimentation. One of the most important aspects of observation and experimentation is measurement; thus, you will be making and using a lot of measurements in this course. As a result, you need to become very comfortable with the process of making measurements and the language that revolves around those measurements. You must also be comfortable with using those measurements in mathematical equations and making sure that you report the results of the equations with a precision that reflects the precision of the original measurements.

If you have already taken a good chemistry course, you have covered what you need to know about measurements and how to use them in mathematical equations. If your previous chemistry course was *Exploring Creation with Chemistry*, you covered all of these topics in that course's first module. However, if you did not take that course, or if you think you might have forgotten some of the material, I will quickly summarize the skills that you need to know. If the summary contains anything that you do not understand, you can visit the course website mentioned in the "Student Notes" portion of the text. When you log into that website, you will see a link that takes you to an electronic version of the first module of *Exploring Creation with Chemistry*. That module gives full explanations for each of the skills that I will discuss in the sections that follow.

The Metric System

In this course, you will use the English system of units occasionally, but you will primarily use the metric system of units. Thus, you must be familiar with the metric units for mass, distance, and time, as well as the prefixes which are used to modify the size of the units.

In 1960, an international committee established the standard units for the measurement of fundamental quantities in science. This standard is called the **System Internationale (SI)** set of units. In this course, it will be most helpful to use SI units. The SI unit for mass is the *kilogram*; the SI unit for distance is the *meter*; and the SI unit for time is the *second*. Later in the course, a few more SI units will be introduced.

The Factor-Label Method

Often, you will come across measurements in the English system that must be converted into the metric system, or you will run into measurements that are in the metric system but are not SI units. Thus, you need to be very familiar with converting from one unit to another. The best way to convert between units is the **factor-label method**, and you must understand this method to take this course.

A quick example of the factor-label method will help illustrate what you need to know. Suppose you need to convert the mass of an object from 4,523 centigrams into the SI unit for mass, which is the kilogram. Here's how you would do it using the factor-label method:

$$\frac{4{,}523\ \cancel{\text{cg}}}{1} \times \frac{0.01\ \cancel{\text{g}}}{1\ \cancel{\text{cg}}} \times \frac{1\ \text{kg}}{1{,}000\ \cancel{\text{g}}} = 0.04523\ \text{kg}$$

If you do not understand how I set that up, why the units cancel the way I have canceled them, or how to get the answer, you need to review the factor-label method.

Using Units in Mathematical Equations

Physics and math are intimately linked. As you progress through this course, you will be using mathematical equations to analyze a host of physical situations. As a result, you need to be completely comfortable using units in mathematical equations. When you add or subtract measurements, you cannot add them unless the units are the same. Thus, an equation like 1.2 m + 3.4 kg is meaningless. There is no way you can add those two measurements.

However, you can multiply or divide measurements whether or not the units are the same. If you have a box with a length of 0.50 m, a height of 0.25 m, and a length of 0.45 m, you can multiply the length, width, and height together to calculate that the box has a volume of 0.056 m^3. If that box has a mass of 5.1 kg, you can divide the mass by the volume to find out that the density of the box is 91 kg/m^3. If you do not understand why the unit for the volume is m^3 or why the unit for the density is kg/m^3, you need to review the use of units in mathematical equations.

Making Measurements

In this course, you will be making some measurements of your own. Thus, you need to know how to read measuring instruments and how to report your measurements with the proper precision. A metric ruler, for example, is usually marked off in increments of 0.1 cm, or 1 mm. However, because you can estimate in between those marks, you can report your answer to a precision of 0.01 cm. Consider, for example, the situation below:

Illustration by Megan Whitaker

The blue ribbon in the figure above is 3.45 cm long. If you do not understand how I got that measurement or why the ribbon starts on the 1 cm mark rather than at the beginning of the ruler, you need to review the process of making measurements.

Accuracy, Precision, and Significant Figures

There is a big difference between the **accuracy** of a measurement and the **precision** of a measurement. You need to understand the difference. You also need to understand how to use **significant figures** to determine the precision of a measurement as well as to determine where to round off your answers when you are working problems. So that you can easily refer back to them, I will summarize the rules of significant figures below.

In order to determine whether or not a figure is significant, you simply follow this rule:

A digit within a number is considered to be a significant figure if:

I. It is non-zero OR
II. It is a zero that is between two significant figures OR
III. It is a zero at the end of the number *and* to the right of the decimal point

When using measurements in mathematical equations, you must follow these rules:

Adding and Subtracting with Significant Figures: **When adding and subtracting measurements, round your answer so that it has the same precision as the *least precise* measurement in the equation.**

Multiplying and Dividing with Significant Figures: **When multiplying and dividing measurements, round the answer so that it has the *same number of significant figures as the measurement with the fewest significant figures*.**

To quickly review how these rules work, consider the following subtraction problem:

$$546.2075 \text{ kg} - 87.61 \text{ kg}$$

The answer to this problem is 458.60 kg. The first number has its last significant figure in the ten thousandths place, while the second has its last significant figure in the hundredths place. Since the second number has the lowest precision, the answer must have the same precision, so the answer must have its last significant figure in the hundredths place. Compare that to the following division problem:

$$\text{Speed} = 3.012 \text{ miles} \div 0.430 \text{ hours}$$

The answer is 7.00 miles/hour. The first number has four significant figures, while the second number has three. Thus, the answer must have three significant figures. If any of this discussion is confusing, please review the concept of significant figures.

Scientific Notation

Since reporting the precision of a measurement is so important, we need to be able to develop a notation system that allows us to do this no matter what number is involved. Suppose you work out an equation, and the answer turns out to be 100 g. However, suppose you need to report that measurement to three significant figures. The number "100" has only one significant figure. So how can you report it to three significant figures? For that, you use scientific notation. If you report 100 g as 1.00×10^2 g, the two zeros are now significant because of the decimal place, so the answer now has three significant figures. If you need to report "100" with two significant figures, you could once again use scientific notation, but this time, you would have only one zero after the decimal: 1.0×10^2 g. You must be very comfortable using scientific notation and determining the significant figures in a number that is expressed in scientific notation.

Mathematical Preparation

In addition to the concepts discussed above, there are certain mathematical skills I am going to assume that you know. You should be very comfortable with algebra, and you need to know the three basic trigonometric functions (sine, cosine, and tangent) and how they are defined on a right triangle. You also need to be familiar with the inverses of those functions ($\sin^{-1}$, $\cos^{-1}$, and $\tan^{-1}$). Please do not go any further in this course until you are comfortable with everything I have mentioned so far. Once again, there is a good review of these concepts (not including the algebra and trigonometry mentioned in this section) posted on the course website.

MODULE #1: Motion In One Dimension

Introduction

As I said in my introductory remarks, the science of physics attempts to explain everything that is observed in nature. Now of course, this is a monumentally impossible task, but physicists nevertheless do the best job that they possibly can. Over the last three thousand years, remarkable advances have been made in explaining the nature of the world around us, and in this physics course, we will learn about many of those advances. This module will concentrate on describing *motion*.

If you look around, you will see many things in motion. Trees, plants, and sometimes bits of garbage blow around in the wind. Cars, planes, animals, insects, and people move about from place to place. You should have learned in chemistry that even objects which appear stationary are, in fact, filled with motion because their component molecules or atoms are moving. In short, the world around us is alive with motion.

In fact, Thomas Aquinas (uh kwy' nus) listed the presence of motion as one of his five arguments for the existence of God. He said that based on our experience, we have found that motion cannot occur without a mover. In other words, in order for something to move, there must be something else that moves it. When a rolling ball collides with a toy car, the car will move because the ball gave it motion. But, of course, the ball would not have been rolling to begin with if it had not been pushed or thrown. Thus, Aquinas says that our practical experience indicates that any observable motion should be traceable back to the original mover. When the universe began, then, something had to be there to start all of the motion that we see today. Aquinas says that God is this "original mover."

While philosophers and scientists can mount several objections to Thomas Aquinas's argument, it nevertheless demonstrates how important motion is in the universe. Thus, it is important for us to be able to study and understand motion. In this module, we will attempt to understand the most basic type of motion: motion in one dimension. Remember from geometry what "one dimension" means. If an object moves in one dimension, it moves from one point to another in a straight line. In this module, therefore, we will attempt to understand the motion of objects when they are constrained to travel straight from one point to another.

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FIGURE 1.1
Thomas Aquinas

Thomas Aquinas (1225-1274) was an Italian philosopher and Roman Catholic theologian. He was a prolific writer, being credited with about eighty important works. In his work entitled *Summa Theologica*, he cites five arguments for the existence of God. The first one is summarized as follows:

"It is certain, and evident to our senses, that in the world some things are in motion. Now whatever is in motion is put in motion by another...If that by which it is put in motion be itself put in motion, then this also must needs be put in motion by another, and that by another again. But this cannot go on to infinity...Therefore it is necessary to arrive at a first mover, put in motion by no other; and this everyone understands to be God." (*Summa Theologica*, Second and Revised Edition, 1920; retrieved from http://www.newadvent.org/summa/100203.htm on 11/14/2003)

Distance and Displacement

When studying the motion of an object, there are a few very fundamental questions you can ask: Where is the object? How fast is it moving? How is the object's motion changing? In physics terminology, we say that the answers to these questions are the object's **position**, **velocity**, and **acceleration**. You might also ask how the object's position has changed. Physicists call that **displacement**.

Displacement - The change in an object's position

I will discuss velocity and acceleration in upcoming sections of this module. For right now, I want to concentrate on displacement.

Suppose you are sitting on the sofa reading a book (maybe even this one), and you suddenly decide that you want to go to the refrigerator for a drink. You get up, and you move to the refrigerator, which is 10 meters away from the sofa. You get your drink and then walk 10 meters back to the sofa. How much distance did you travel in your quest for liquid refreshment? Well, you walked 10 meters there and 10 meters back, so you walked a total of 20 meters. After everything was finished, what was your total displacement? *It was zero meters*!! You see, before everything began, you were at the sofa. Since you started there, we can define it as your initial position. You moved to the refrigerator, at which point you were 10 meters displaced from the sofa. However, when you turned around and came back, you ended up at exactly the same point from which you started. In the end, then, you were 0 meters from your starting position; thus, your displacement was 0 meters.

You see, then, that the concept of displacement includes information about direction, whereas the concept of distance does not. In the situation we just imagined, you walked a *distance* of 20 meters, but your *displacement* was 0 because you walked 10 meters in one direction and then another 10 meters in precisely the opposite direction. Since the displacement in one direction canceled the displacement in the opposite direction, your total displacement was 0. When a physical quantity carries information concerning direction we call it a **vector** (vek' ter) **quantity**. When the physical quantity does not carry information concerning direction, we call it a **scalar** (skay' ler) **quantity**.

Vector quantity - A physical measurement that contains directional information

Scalar quantity - A physical measurement that does not contain directional information

Thus, distance is a scalar quantity, and displacement is a vector quantity.

When dealing with displacement, we must find some mathematical way to denote the direction that is inherent in the measurement. The way we will do this is to label displacement in one direction positive and displacement in the opposite direction negative. That way, when you add displacements together, motion in one direction will cancel motion in the opposite direction. Thus, we could say that in the situation discussed above, your displacement was +10 meters when you moved from the sofa to the refrigerator and -10 meters when you moved the opposite direction from the refrigerator to the sofa. Your total displacement, then, was +10 meters plus -10 meters, which is 0.

What's really nice about this mathematical way of noting direction is that it doesn't really matter which direction you label as positive or which you label as negative. We could just as easily have said that your displacement when you arrived at the refrigerator was -10 meters. That would mean that your displacement when you moved from the refrigerator to the couch was +10 meters. The total displacement would still be 0. Thus, it doesn't matter which direction you label as positive, as long as you keep it consistent. To make sure that you understand what I mean, consider Figure 1.2:

Illustrations from the MasterClips collection

FIGURE 1.2
Displacement and Distance

Two cars start out at exactly the same location.

After a given amount of time, each car has traveled 500 meters. The *distance* that they have traveled is the same. However, since they traveled in different directions, their *displacements* are different.

In the figure, two cars start at the same location, but the blue car is heading west, while the red car is heading east. After a given amount of time, each car has traveled a total distance of 500 meters. Although both cars have traveled the same distance, their displacements are not the same, because they traveled in opposite directions. Suppose we define east as the positive direction. In that case, the red car would have a displacement of +500 meters, and the blue car would have a displacement of -500 meters. Alternatively, we could define west as the positive direction. If we did that, the blue car would have a displacement of +500 meters, and the red car would have a displacement of -500 meters.

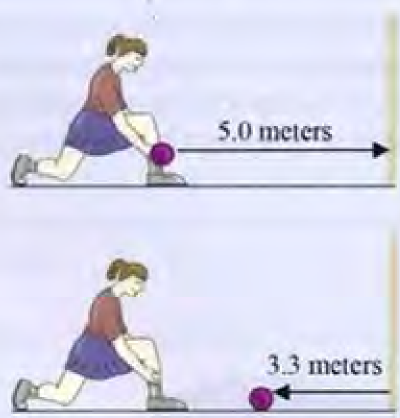
Does it matter which car has a negative displacement and which has a positive displacement? *No, it really doesn't!* Which direction you define as positive is not important. The only thing that is important is that you *remember the definition and use it consistently throughout your analysis.* If you define east as positive, that's fine, but just remember that in the end, any displacement which ends up positive means the displacement is to the east, and any displacement that ends up negative means the displacement is to the west. Alternatively, if you define west as positive, just remember that any displacement which turns out to be positive means the displacement is to the west, and any displacement that ends up negative means the displacement is to the east.

This can get a little confusing if you are not completely comfortable with the idea of using positive and negative signs to denote direction, so I want to show you how to keep all of this straight. Study the following example to see that the final answer is really independent of which direction you define as negative, as long as you are consistent in your definition. After you have studied the example, solve the "On Your Own" problem that follows it to make sure you understand this important concept.

EXAMPLE 1.1

Illustration by Megan Whitaker

A child is 5.0 meters away from a wall and rolls a ball towards it. The ball hits the wall and bounces back, rolling 3.3 meters before coming to a halt. What is the total distance covered by the ball? What is the ball's displacement ?



The total distance is easy to calculate. The ball rolled 5.0 meters to reach the wall and 3.3 meters in the other direction after bouncing back. The total distance is calculated as follows:

Total distance = 5.0 meters + 3.3 meters = 8.3 meters

Calculating the displacement is a bit more difficult, however. To do this, we must first define directions. I will say that motion from the child to the wall represents positive displacement while motion from the wall to the child is negative displacement. Thus, the ball first had a displacement of +5.0 meters and then a displacement of -3.3 meters. The total displacement, then, is:

Total displacement = 5.0 meters + -3.3 meters = 1.7 meters

The displacement is positive, so the ball is <u>1.7 meters away from the child, in the direction of the wall</u>.

Alternatively, I could have said that motion from the child towards the wall represented *negative* displacement. In that case, the ball would have had a -5.0 meters displacement followed by a +3.3 meters displacement. This would indicate a total displacement of -1.7 meters. You might think that this is a different answer than the one I got previously, because this one is negative. Remember, however, what negative displacement means in this case. It means displacement *from the child towards the wall*. Thus, my answer is still <u>1.7 meters away from the child, in the direction of the wall</u>. As long as you stay consistent, then, your answer will be the same regardless of which direction you say is positive and which is negative. The trick is to give your answer in relation to the initial position, not with just a positive or negative sign.

ON YOUR OWN

1.1 An ant starts at his anthill and walks 15.2 cm to a crust of bread. He takes the bread, turns around, and walks back towards his anthill. He stops after he has traveled 3.8 cm and eats part of the crust of bread. What is the total distance he has traveled up to that point? What is the total displacement?

<u>Speed and Velocity</u>

Now that you have some idea of what displacement is, you can begin to learn about velocity.

<u>Velocity</u> - The time rate of change of an object's position

This definition may sound a bit strange, but it is really easy to understand. Velocity simply tells us how quickly an object's position is changing. That's what "time rate of change" means. In order to determine this, all you need to do is take the change in position and divide it by the time it took to make that change. Mathematically, we could say:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} \tag{1.1}$$

where "**v**" represents the velocity, "**x**" represents the position, and "t" represents time. The symbol "Δ" represents the capital Greek letter "delta" and means "change in." Thus, "Δ**x**" means the change in position, while "Δt" means the change in time. Now remember, the change in an object's position is defined as its displacement, so "Δ**x**" also means "displacement."

There are two very important things you need to learn about Equation (1.1). First, since we calculate velocity by taking displacement (usually measured in meters) and dividing by time (usually measured in seconds), the SI unit for velocity is meters/second ("meters per second"). Thus, if I travel for 30.0 seconds and my total displacement during that time is 60.0 meters to the west, my velocity is 60.0 meters ÷ 30.0 seconds, or 2.00 meters/second (abbreviated as m/sec) to the west.

The second thing you need to learn about this equation is that velocity and displacement are both vector quantities. You have already learned that about displacement, and since you use displacement to calculate velocity, it only makes sense that velocity is also a vector quantity. Whenever you use velocity, then, you must be sure to keep track of direction. Mathematically, we will do it the same way we did with displacement. Motion in one direction will be noted as positive velocity, while motion in the opposite direction will be written as negative velocity.

What about time in Equation (1.1)? Is it a vector or a scalar quantity? Well, if you think about it, time only goes one way. As far as we can tell, time cannot go in reverse. Thus, since time does not have a direction attached to it, it is considered a scalar quantity. This is why I have written "**v**" and "**x**" in boldfaced type but kept "t" in normal type. The boldfaced type indicates that "**v**" and "**x**" are vector quantities. Since t is not in boldfaced type, you can assume it is not a vector. This kind of notation will exist throughout the rest of the course. When I write a variable in boldfaced type, it will mean that the variable is a vector quantity. If the variable is not in boldfaced type, it will be considered a scalar quantity.

Now it is very important that you do not confuse the concept of velocity with the concept of speed. Just as distance and displacement are different quantities, velocity and speed are also different quantities.

<u>Speed</u> - The time rate of change of the distance traveled by an object

In other words, to determine the speed of an object, you take the total distance traveled and divide by the time it took to travel that distance. Mathematically, we could say:

$$\text{speed} = \frac{\Delta d}{\Delta t} \tag{1.2}$$

where "d" represents distance, and "t" represents time. Notice that none of the variables in this equation are written in boldfaced type. This indicates that there are no vectors in Equation (1.2), and that is the main difference between velocity and speed. While velocity is a *vector quantity*, speed is a *scalar quantity*. Thus, although Equations (1.1) and (1.2) look very similar, speed and velocity are quite different, because one is a vector and one is not. Let's study a couple of examples to make sure you understand these distinctions.

EXAMPLE 1.2

You hop on your bicycle and pedal 151.1 meters to the end of your street in 25.2 seconds. You then turn around and pedal back to where you started. If the return trip takes 27.1 seconds, what was your speed and what was your velocity over the course of the entire bike ride?

We will solve for speed first, because that's a little easier. According to Equation (1.2), we can figure out speed by taking the distance traveled (Δd) and dividing by the time it took to travel that distance (Δt). If the street is 151.1 meters long and you traveled to the end and back, you traveled a total distance of 151.1 m + 151.1 m, or 302.2 m. The total time it took to travel that distance was 25.2 seconds + 27.1 seconds or 52.3 seconds. Thus, according to Equation (1.2):

$$\text{speed} = \frac{\Delta d}{\Delta t} = \frac{302.2\ \text{m}}{52.3\ \text{sec}} = 5.78\ \frac{\text{m}}{\text{sec}}$$

Now remember, we must take significant figures into account when doing calculations. In this case, we are dividing, so we count significant figures. Since 302.2 has four significant figures, and 52.3 has three significant figures, we must report our answer to three significant figures. That's why the speed over the course of the entire trip was <u>5.78 m/sec</u>.

Calculating velocity, however, is quite another matter. Velocity is determined by taking the displacement and dividing by the time it took to achieve that displacement. By the time that the bike ride was over, your displacement was zero, because you ended up back where you started. Thus, Equation (1.1) becomes:

$$v = \frac{\Delta x}{\Delta t} = \frac{0\ \text{m}}{52.3\ \text{sec}} = 0\ \frac{\text{m}}{\text{sec}}$$

In the end, then, while your total speed was considerable (5.78 m/sec), your velocity was zero! It might sound strange that you could ride a bike with zero velocity, but once again, remember that velocity is a vector quantity. When your velocity is zero, it means simply that your total displacement was zero. Thus, even though you pedaled a lot, you ended up going nowhere by the end of your ride, so your displacement and velocity were both zero!

A sprinter runs the 200-meter (2.00×10^2 m) dash in 24.00 seconds. He then turns around and walks 15 meters back towards the starting line in order to talk to his coach. Because he is so tired, it takes him 25 seconds to walk that 15 meters. What was the sprinter's velocity during the 200-meter dash? What was his velocity when he walked back to talk to the coach? What was his velocity for the entire trip?

In this case, we are asked to calculate velocity, so we will only be using Equation (1.1). Once again, we are dealing with vector quantities here, so we must define direction. I will call motion from the starting line to the finish line positive motion. This makes motion from the finish line to the