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.

Image in the public domain

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

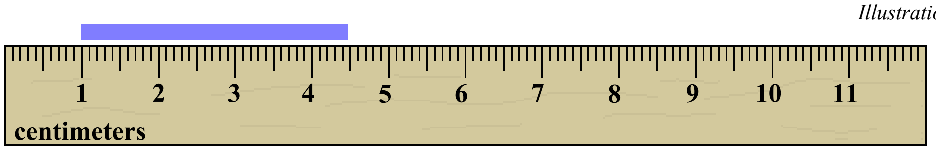
Physics and math are intimately linked. As you progress through this course, you will be using mathematical equations to analyze a host of physical situations. As a result, you need to be completely comfortable using units in mathematical equations. When you add or subtract measurements, you cannot add 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 cube 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 cube has a mass of 5.1 kg, you can divide the mass by the volume to find out that the density of the cube 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

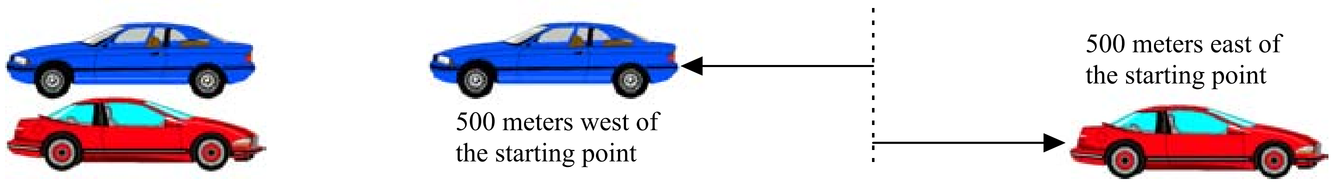
Thus, distance is a scalar quantity, and displacement is a vector quantity.

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:

FIGURE 1.2
Displacement and Distance

Illustrations from the MasterClips collection



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.

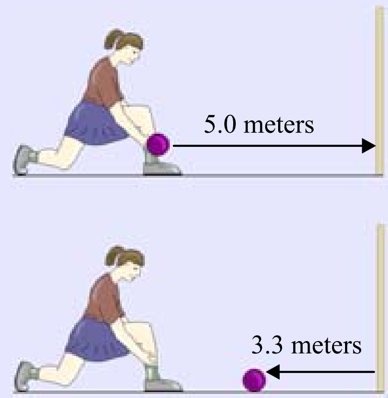
In the figure, two cars start at the same location, but the blue car is heading west, while the red car is heading east. After a given amount of time, each car has traveled a total distance of 500 meters. Although both cars have traveled the same distance, their displacements are not the same, because 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 balls 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.

Speed - 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:

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

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 starting line negative motion. The first part of the question asks us to calculate the sprinter's velocity during the 200-meter dash. During that time, the sprinter was moving from the starting line to the finish line. Thus, his displacement was 2.00×10^2 meters. It took him 24.00 seconds to make the run, so Equation (1.1) becomes:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{2.00 \times 10^2 \text{ m}}{24.00 \text{ sec}} = 8.33 \frac{\text{m}}{\text{sec}}$$

Three significant figures in 2.00×10^2 m limit our answer to three significant figures. We could therefore say that his velocity was <u>8.33 m/sec in the direction of the finish line</u>.

The second part of the question asks us to calculate his velocity as he is walking back to speak with his coach. During that time, he walked towards the starting line, so his displacement was negative:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{-15 \text{ m}}{25 \text{ sec}} = -0.60 \frac{\text{m}}{\text{sec}}$$

Note that both -15 m and 25 seconds have two significant figures, so our answer can have only two significant figures. Thus, we must say that his velocity was <u>0.60 m/sec towards the starting line</u>.

Finally, the problem asks us to determine his velocity over the entire trip. You might think that we could simply average the two velocities that we already calculated, but that would not be correct. The only way we can properly calculate the velocity is to determine the displacement and then divide by the time that elapsed. When the sprinter finished the race, his displacement was 2.00×10^2 meters. However, when he walked back to talk to his coach, his displacement changed by -15 meters. Thus, his total displacement was 2.00×10^2 m + -15 m = 185 m in the direction of the finish line. Now before we use this in Equation (1.1), I want to make sure that you understand how the significant figures work. Since we are adding these numbers, we use the rule of addition and subtraction, which says that you report your answer with the same precision as the least precise number in the problem. The initial displacement (2.00×10^2 m) has its last significant figure in the ones place. Don't let the scientific notation fool you: $0.01 \times 10^2 = 1$. Thus, the second zero after the decimal is in the ones place. The second displacement (-15 m) has its last significant figure in the ones place. Thus, the precision of each measurement is to the ones place, so our answer must be reported to the ones place. That's why it is 185 m. If this does not make sense, you might want to review the section on significant figures in the module that is posted on the course website.

Now that we have the significant figures out of the way, let's finish the problem. The total time it took to achieve a displacement of 185 m was 24.00 seconds + 25 seconds = 49 seconds. Once again, note that because 25 sec is precise only to the ones place, our answer must be reported to the ones place. Using the displacement and change in time that we just calculated, Equation (1.1), becomes:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{185 \text{ m}}{49 \text{ sec}} = 3.8 \frac{\text{m}}{\text{sec}}$$

Since the velocity is positive, we know that even though he walked back a little, his overall velocity was still <u>3.8 m/sec in the direction of the finish line</u>.

Make sure you understand these concepts by solving the following "On Your Own" problem.

ON YOUR OWN

1.2 A mail carrier drives down a street delivering mail. She travels 3.00×10^2 meters down the street in 332 seconds. She then turns around and heads back up the street, but because of the way the mailboxes are placed, she only needs to travel 208 meters in that direction, and that trip takes her only 2.30×10^2 seconds. What was her velocity as she traveled down the street? What was it as she traveled up the street? What was her velocity for the entire trip?

Now of course, Equation (1.1) has more applications than the ones you have seen so far. Study the next example and solve the "On Your Own" problem that follows in order to see how other types of problems can be solved using this equation.

EXAMPLE 1.3

A jogger runs down a long, straight country road at 2.3 m/sec. If she jogs in that direction for 15.3 minutes, how far does she run?

Part of the trick to solving physics problems is learning how to read the question so that you see what you are trying to solve for. In this example, a couple of words should jump out at you. First, you are given a speed, but you are also given direction because the words "straight" and "down" are used. Thus, the 2.3 m/sec is a velocity, because direction is included. The problem also gives you time, but it is not in units that are consistent with the velocity. The velocity is given in m/sec, but the time is given in minutes. To be able to use both of these pieces of information in any solution, the units must be consistent. We therefore must convert one of these quantities into different units. Since m/sec is the standard, I won't convert it. Instead, I will convert 15.3 minutes into seconds:

$$\frac{15.3\ \cancel{\text{min}}}{1} \times \frac{60\ \text{sec}}{1\ \cancel{\text{min}}} = 918\ \text{sec}$$

Remember that the "60" and the "1" in the conversion relationship are exact. There are exactly 60 seconds in a minute. Thus, both "60" and "1" really have an infinite number of significant figures (60.000… and 1.000…), even though they are not listed. Thus, the number of significant figures in the original measurement limits the number of significant figures in the answer.

Now that we have our units straight, we can continue. The problem asks us to determine how far the jogger will go. Well, "how far" is another way of saying "how much displacement." After all, if she runs, say, 100 meters, her displacement from the place that she started will be 100 meters. Thus, we are given velocity and time and asked to determine displacement. Equation (1.1) relates these three quantities. We will therefore use Equation (1.1), substituting the values that we already know:

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

$$2.3\,\frac{\text{m}}{\text{sec}} = \frac{\Delta\mathbf{x}}{918\ \text{sec}}$$

Now we can use algebra to rearrange this equation and solve for the displacement ($\Delta\mathbf{x}$):

$$2.3\,\frac{\text{m}}{\cancel{\text{sec}}} \times 918\ \cancel{\text{sec}} = \Delta\mathbf{x}$$

$$2.1\times 10^{3}\ \text{m} = \Delta\mathbf{x}$$

So the jogger's displacement is 2.1×10^3 m down the road. Thus, the jogger ran $\underline{2.1 \times 10^3\ \text{m}}$. Please note that I did not need to use scientific notation in the answer. I could have said 2,100 m. Either way, the displacement is the same, and the number of significant figures is the same. So either answer is correct.

Do you see how we solved this problem? We read it carefully, and we picked out words that told us what quantities we had and what quantities we needed to determine. We then found an equation that related these quantities and used algebra to solve the equation. This is the way you solve physics problems. Try it yourself with the following "On Your Own" problem.

ON YOUR OWN

1.3 A boat travels straight down a river at a speed of 15 m/sec. If the boat travels a distance of 34.1 km, how long was the boat ride?

Average and Instantaneous Velocity

In "On Your Own" problem 1.2 and in the example preceding it, we got answers that you might think are a bit strange. In the example, for instance, the sprinter's velocity over the entire trip was 3.8 m/sec in the direction of the finish line. You might find it odd that despite the fact that the sprinter traveled in both directions, his overall velocity was in the direction of the finish line. If you find it strange, don't worry. That's because we haven't discussed the difference between instantaneous and average velocity. We'll do that now.

Instantaneous velocity - The velocity of an object at one moment in time

Average velocity - The velocity of an object over an extended period of time

These two concepts of velocity are quite different. To see how different they are, perform the following experiment.

EXPERIMENT 1.1
Measuring Average Velocity

Note: A sample set of calculations is available in the solutions and tests guide. It is with the solutions to the practice problems.

Supplies:

- Safety goggles
- A stopwatch (A watch with a second hand will do.)
- A pile of books between 6 and 9 centimeters thick
- A wooden board, about 1 meter long (Any long, flat surface that you can prop up on one end will do. It needs to be as smooth as possible.)
- A pencil (Anything that you can use to mark the board will do.)
- A ball that will easily roll down the board

1. Choose the smoothest side of the board and clear it of any debris.
2. Make a mark on the board in the center. Make sure the mark is easy to see.
3. Prop the board up on one end with the books, so that the board forms an incline as shown below. In a moment, you will be rolling the ball down the incline. Your experiment should look something like this:

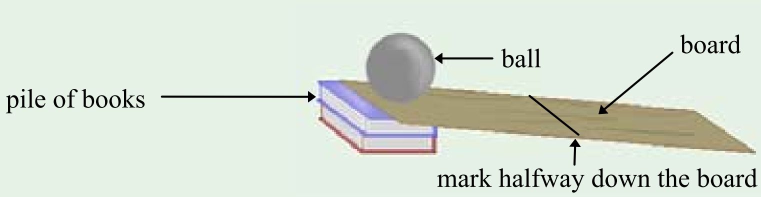


Illustration by Megan Whitaker

4. Measure the distance from the top of the board to the mark halfway down the board. Make sure you record the distance to the proper precision. Since you can estimate between the lines, most metric rulers can be read to 0.01 cm. Call this distance "d_1."
5. Measure the distance from the mark to the end of the board as well, once again writing your answer with the proper precision. Call it "d_2." If you really made the mark in the center of the board, d_1 and d_2 should be the same. If not, don't worry about it. They do not have to be equal.
6. Once you have set up your experiment and made both distance measurements, hold the ball on the very top of the board and be ready to release it. At the exact moment that you release the ball, start the stopwatch. Stop the watch when the ball hits the mark.
7. Write down the time you measured. Be as precise as the stopwatch allows.
8. Repeat this measurement four more times. After you have a total of five measurements for the time, average them and write down your answer. Why did I have you measure the same thing five times and average the result? Well, there are many errors which can occur when you make these kinds of measurements. Most likely, you did not start the stopwatch at *exactly* the time that you released the ball. You probably started it a bit before or a bit after. In the same way, you probably did not stop it at *exactly* the time that the ball reached the mark. You probably stopped it shortly before or shortly after. These types of errors (called "random errors") make a single measurement inaccurate. However, if you make several such measurements and average the results, the random errors in the individual measurements will (to some extent) cancel out, making the average a better estimate of the true value. The more measurements you make, the better this works.
9. Once you have that average, divide it into the distance from the top of the board to the first mark (d_1). Let's say that motion down the board is positive. That way, the distance you measured is also the ball's displacement. Thus, the calculation you just made took displacement and divided it by time, which gives you the velocity of the ball as it traveled from the top of the board to the first mark. Call this velocity v_1.

10. Hold the ball at the top of the board again, and be ready to release it. This time, however, *do not start the stopwatch until the ball hits the first mark*. Stop the watch when the ball hits the end of the board. Do this measurement a total of five times as well, and once again, average the results.
11. Take the average and divide it into d_2. This will give you the velocity of the ball as it traveled down the second half of the board. Call it v_2.
12. Finally, do the same thing again, this time starting the watch the instant that you release the ball and stopping the watch once the ball hits the end of the board.
13. Average the five results and divide that average into the total length of the board ($d_1 + d_2$). This is the velocity of the ball over the entire trip. Call it v_3.
14. Clean up your mess, but save the supplies, because you will use them again in Experiment 1.2.

Now let's figure out what this experiment demonstrates. Compare your three velocities. If you did the experiment correctly, v_1 should be less than v_2. In addition, v_3 should be between v_1 and v_2. Why? Well, the ball was speeding up the whole time it traveled down the board. Thus, v_1 is the lowest because the ball had not sped up all of the way by the time it hit the first mark. V_2 was larger than v_1 because the ball had more time to speed up traveling down the second half of the board. The total velocity (v_3) was the *average* of the two velocities you measured. That's why it falls in between them.

So, which velocity (v_1, v_2, or v_3) is the velocity of the ball as it traveled down the board? The answer is that *all three* are. However, they are *measured over different time intervals*. When we take the total displacement and divide by the time it takes to make that displacement, we are calculating the *average velocity*. V_1 is the average velocity of the ball while it traveled down the first half of the board; v_2 is the average velocity of the ball as it traveled down the second half of the board; and v_3 is the average velocity as the ball traveled down the entire board.

Now suppose we divided the board into five sections instead of just two, and suppose we measured the velocity of the ball as it traveled through each of the five sections, determining v_1 - v_5, as well as the average across the entire board, v_6. You can probably predict the results: v_1 would be the smallest, v_2 - v_4 would each be progressively larger, and v_5 would be the largest. In addition, v_6 would be in between v_1 and v_5.

Now suppose that we were able to divide the board into an *infinite* number of *extremely tiny* sections, and suppose further that we could measure the velocity as the ball traveled through each of these infinitesimally small sections. What would we have then? Well, we would have an incredibly bored and frustrated student, but we would also have an infinite number of velocities, each of which would be slightly greater than the one before. At that point, however, we would no longer have *average* velocities. We would have *instantaneous* velocities.

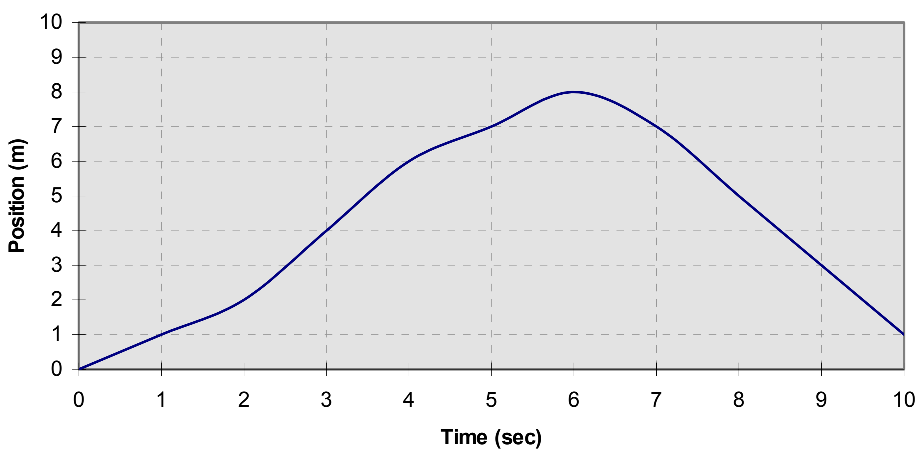
That's the difference between instantaneous and average velocity. Instantaneous velocity represents the velocity measured over an infinitesimally small time interval. Of course, it is impossible for us to measure instantaneous velocity, but the smaller the time interval, the closer the average velocity is to the instantaneous velocity. Consider the results of your experiment again. V_3 was the average velocity as the ball traveled down the entire board. V_1 was the average velocity as the ball traveled down the first half of the board, and v_2 was the average velocity as the ball traveled down the second half of the board. Since v_1 and v_2 were measured over shorter time intervals than v_3, v_1 and v_2 are *closer* to instantaneous velocities than is v_3. If we divided up the board into five sections instead of two, the velocities v_1 - v_5 would each be closer to instantaneous velocities than were the v_1 and v_2 you measured in your experiment.

This is why you can get strange answers like the one we got in Example 1.2. The last velocity that we calculated in the example was the average velocity of the sprinter. This, in effect, averaged the positive and negative velocities that we calculated in the first part of the example. Since the sprinter ran faster and longer in the positive direction, the average velocity turned out to be positive, even though the sprinter traveled in both directions. Thus, average velocity is calculated over a long time span, while instantaneous velocity is calculated over an infinitely short time span. Since it is impossible to measure displacement and time over an infinitely short time span, we can never really measure instantaneous velocity. Thus, all of the velocity measurements that we can make are really *average* velocities. However, the smaller the time span that we use to measure average velocity, the closer the average velocity is to the instantaneous velocity.

Although it is not possible to *measure* instantaneous velocity, we can estimate it rather easily by reading a graph. Consider, for example, the graph in Figure 1.3:

FIGURE 1.3

A Position-Versus-Time Graph



In this graph, the position of an object is plotted on the y-axis while time is plotted on the x-axis. Thus, the curve represents an object's position at various time intervals. If you look at the graph, you will see that the object starts at zero and then moves in a positive direction to a maximum position of 8.0 meters from its starting point. It reaches that maximum position in 6.0 seconds. At that point, the object's position begins to decrease. The only way that can happen is if it begins to move back towards the starting point. In other words, it begins to move in the *negative* direction. Thus, after it reached a position of 8.0 meters from its starting point, the object must have turned around and moved in the opposite direction.

Now, despite the fact that the velocity is not plotted in this graph, it can be determined from the graph. In fact, you can actually get a good feel for the meaning of instantaneous velocity by looking at this graph. I'm getting ahead of myself, however. How can you determine velocity from such a graph? Well, according to Equation (1.1), you can calculate velocity by taking the change in position (the displacement) and dividing by the change in time. On this graph, position is plotted on the y-axis and time is plotted on the x-axis. Thus, to get velocity, we need to take the change in the y coordinate and divide it by the change in the x coordinate. What's another name for the quantity you get when you take the change in y and divide by the change in x? It's the *slope!* Thus, we come to a very important fact:

The slope of a position-versus-time curve is the velocity.

What does this mean? Well, we can calculate the slope of the curve in Figure 1.3, and that represents the velocity of the object. Thus, suppose we looked at the object's position at a time of 1.0 seconds. According to the graph, the position is 1.0 m from the starting point. At 6.0 seconds, however, the position is 8.0 meters from the starting point. Thus, the slope of the curve during that time interval is:

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{8.0\text{ m} - 1.0\text{ m}}{6.0\text{ sec} - 1.0\text{ sec}} = 1.4\frac{\text{m}}{\text{sec}}$$

Now remember, since the slope of a position-versus-time curve is the velocity, the average velocity of the object during the time interval of 1.0 second to 6.0 seconds was 1.4 m/sec.

On the other hand, suppose we examined the time interval between 0.0 and 1.0 seconds. At zero seconds, the position was 0.0, while at 1.0 seconds, it was 1.0 m. The slope of the curve over that time frame (which is the velocity), then, is:

$$\text{slope} = \mathbf{v} = \frac{\text{rise}}{\text{run}} = \frac{1.0\text{ m} - 0.0\text{ m}}{1.0\text{ sec} - 0.0\text{ sec}} = 1.0\frac{\text{m}}{\text{sec}}$$

Which of those two velocities is closest to an instantaneous velocity? The second one, because it is calculated over a smaller time interval. If we reduced the time interval even more, we would get even closer to a true instantaneous velocity. Taking this reasoning to an extreme, when the time interval is infinitesimally small, the velocity would truly be instantaneous. Thus, if we were to look at a position-versus-time curve at a single point in time, we could estimate the instantaneous velocity by estimating the slope of the curve at that point.

Now if all of this seems a bit confusing, don't worry about it. We'll get lots of practice at examining such graphs, so you'll become a veritable expert at this stuff. Let's look at Figure 1.3 again and look at another time interval. Specifically, let's look at the time interval between 5.9 and 6.1 seconds. What's the velocity during that time interval? Well, according to the graph, the object's position seems to stay steady at 8.0 m during that time interval. The velocity, then, is:

$$\text{slope} = \mathbf{v} = \frac{\text{rise}}{\text{run}} = \frac{8.0\text{ m} - 8.0\text{ m}}{6.1\text{ sec} - 5.9\text{ sec}} = 0.0\frac{\text{m}}{\text{sec}}$$

This velocity is very close to instantaneous velocity, because the time interval is very short.

In order to make you truly sick of all of this, let's look at one more time interval. What is the average velocity during the time interval of 7.0 seconds to 10.0 seconds? According to the graph, the object's position falls from 7.0 m to 1.0 m over that time interval. The velocity, then, is:

$$\text{slope} = \mathbf{v} = \frac{\text{rise}}{\text{run}} = \frac{1.0\text{ m} - 7.0\text{ m}}{10.0\text{ sec} - 7.0\text{ sec}} = -2.0\frac{\text{m}}{\text{sec}}$$

What does the negative sign mean? It means that the object is *moving in the opposite direction* during this time interval compared to the others we have examined so far. So you see, we can learn a lot about the velocity of an object by looking at a position-versus-time graph.

Before we move on, I need to make a quick point about significant figures. Note that in all of the calculations I have done so far, I have reported both the position and the time with a precision that goes out to the tenths place. Why did I do that? Well, when you learned about making measurements, you should have been told that when you read numbers from a scale (or a graph), you should be able to estimate in between the markings of the scale (or graph). This gives you one more decimal place than what is marked off. Notice that the graph in Figure 1.3 is marked off in meters and seconds. By estimating between the marks, we can determine position to tenths of a meter and time to tenths of a second. Thus, that is the precision that I must use when I read the position and time from the graph.

Now, let's move on to thinking about the *instantaneous* velocity of the object. Once again, look at the graph in Figure 1.3. You should remember from algebra that the steeper a curve rises or falls, the larger its slope is. If the curve rises, its slope is positive, and if the curve falls, its slope is negative. Finally, when the curve is flat, its slope is zero. If we remember these facts, we can answer some pretty fundamental questions about the motion of an object when examining a position-versus-time graph.

For example, when does the object reach its maximum speed? Well, if we look at the figure, the graph seems to be steepest between 3.0 and 3.8 seconds. During that time interval, the speed is at its maximum value. Now remember, it doesn't matter whether the curve is rising or falling when trying to determine maximum speed. If the curve happens to be steepest as it is falling, that would be the maximum speed. Since the negative sign simply tells us direction, we don't consider it when determining the speed, because speed is not a vector quantity.

Where is the object's speed at its minimum? Once again, we don't worry about whether the velocity is positive or negative, because the sign just tells us direction. Thus, the velocity is lowest where the curve is the least steep. That obviously occurs from 5.9 to 6.1 seconds, where the curve is flat.

We can also compare instantaneous velocities using the graph in Figure 1.3. For example, which is larger, the instantaneous velocity at 4.5 seconds or the instantaneous velocity at 8.5 seconds? Once again ignoring the positive and negative signs because they simply tell us direction, the curve is obviously steeper at 8.5 seconds than it is at 4.5 seconds. Therefore, the instantaneous velocity of the object is greater at 8.5 seconds than it is at 4.5 seconds.

Sometimes, we can actually give a value for the instantaneous velocity by simply looking at the graph. For example, what is the instantaneous velocity at 6.0 seconds? At that time, the curve is flat. Whenever a curve is flat, its slope is zero. Thus, the instantaneous velocity of the object at 6.0 seconds is zero. Also, consider the time interval between 7.0 seconds and 10.0 seconds. During that time, the curve looks like a straight line. Well, in algebra you should have learned that the slope of a straight line is the same no matter where you are on the line. Since we already calculated that the slope of the curve during this time interval is -2.0 m/sec, we can say that the slope of the curve at any point from 7.0 seconds to 10.0 seconds is -2.0 m/sec. Thus, the instantaneous velocity at, say, 8.2 seconds is also -2.0 m/sec.

Since we can learn so much about the velocity of an object from these curves, we need to study them in detail. Study the next example and then do the "On Your Own" problems that follows in order to make sure you can interpret graphs like these.

EXAMPLE 1.4

Consider an object in motion whose position-versus-time graph is as follows:

During what time interval is the object's speed the greatest?

To answer this question, we simply look for the steepest part of the graph. The curve is clearly steepest from 10.0 to 11.0 seconds, so that's the time interval in which the object is moving with the greatest speed. Now remember, the fact that the slope is negative during that time interval simply tells us the direction in which the object is moving. We don't consider the *sign* of the slope in determining the *speed* of the object. Thus, even though the *velocity* is negative, the object's *speed* is greatest from 10.0 to 11.0 seconds.

How many times did the object change directions?

The slope of the curve starts out positive (because the curve is rising), so the object begins by moving in a positive direction. At 4.0 seconds, however, the slope becomes negative (because the curve is falling). This means that the object starts to move in the opposite direction at that time, because the velocity changed direction. That is the first time the object changes direction. At 11.8 seconds, the slope changes from negative back to positive, indicating another direction change. Thus, the object changed direction twice.

What is the instantaneous velocity of the object at 11.8 seconds?

At 11.8 seconds, the curve is flat. Thus, the velocity is 0.0 m/sec.

What is the instantaneous velocity of the object at 6.0 seconds?

During the interval of 5.0 to 9.0 seconds, the curve looks like a straight line. Thus, the slope at any point along that part of the curve is the same. We can therefore calculate the average velocity from 5.0 to 9.0 seconds and, since the velocity stays the same throughout that time interval, that will also be the instantaneous velocity at any time during that interval, including 6.0 seconds.

To read the numbers from the graph, we need to realize that the graph is marked off in meters and seconds, so I can read both the position and the time to the tenths place. The position at 5.0 seconds is 4.0 meters according to the graph, and the position at 9.0 seconds is 0.0 meters. The average velocity, then, is:

$$\text{slope} = \mathbf{v} = \frac{\text{rise}}{\text{run}} = \frac{0.0\text{ m} - 4.0\text{ m}}{9.0\text{ sec} - 5.0\text{ sec}} = -1.0\ \frac{\text{m}}{\text{sec}}$$

This means that the instantaneous velocity at 6.0 seconds is also -1.0 m/sec.

ON YOUR OWN

Consider the following position-versus-time curve:

1.4 Is the object moving faster at 3.5 seconds or at 8.5 seconds?

1.5 How many times does the object change directions?

1.6 What is the instantaneous velocity at 1.0 seconds?

Before we leave this section, I must point something out. Often when students are studying introductory physics, they think that the problems they work out are useless exercises. Nothing could be further from the truth! Nearly every aspect of physics has practical applications. Students, however, are not knowledgeable enough to realize what they are. For example, students often complain that the position-versus-time graphs we just learned are a waste of time because there are no practical uses for them. How wrong these students are!

Race-car drivers spend hours of time on the track, trying to determine the best way to negotiate the curves and straightaways to get the best time possible. It turns out that while they are on the track, computers keep measuring the car's position and time. At the end of the run, the driver and his team study the position-versus-time graph very carefully. You see, by looking at the slope of the curve, the driver can easily see where the car slowed and where it sped up. If the car was slowing down in the wrong place, studying the position-versus-time curve will show that, and the driver can adjust his strategy accordingly. So, now that you understand these position-versus-time curves, you could help a race car driver develop strategies for his next race!

Velocity Is Relative

Now if all of this velocity talk hasn't been confusing enough, there is one more concept that we must cover. One of the most important things to realize about velocity is that it is *relative*. What does that mean? The best way to illustrate how velocity is relative is by considering an example. Let's suppose you've just finished visiting your grandmother's house, and you get in the family car to drive away. You are riding in the passenger's seat next to your father, who is driving. Your grandmother, sorry to see you go, has come out of the house and is standing in front of the car waving good-bye. As the car backs out of the driveway, you are looking at your grandmother, waving good-bye as well. Now, answer this one simple question: Are you moving?

Your first instinct is probably to say, "Well yes, of course I'm moving, because the car is backing out of the driveway!" Wait a minute, though. Aren't you actually sitting still? If your father looks at you, does he think that you're moving? Probably not. After all, as far as he can see, you are sitting still right next to him. You don't seem to move at all. From your grandmother's point of view, however, you are moving. You are moving away from her. That's the point. As far as your father is concerned, you don't seem to be moving at all. From your grandmother's point of view, however, you are, indeed moving. Thus, your father thinks that your velocity is zero, while your grandmother sees that you have a velocity that is greater than zero and directed away from her.

This is what we mean when we say that velocity is relative. It depends on who is observing that velocity. Since your father is in the car with you, you are both moving with the exact same velocity. As a result, your position relative to him never changes. When position doesn't change, velocity is zero. Thus, your father thinks that your velocity is zero. On the other hand, your position relative to your grandmother is changing. As a result, she sees a velocity greater than zero, directed away from her. Thus, velocity can only be determined relative to an observer.

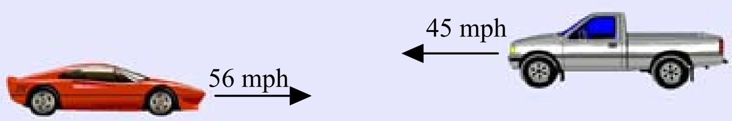
"Now wait a minute," you might be saying, "don't I *really* know that my father and I are moving? After all, we are in the car." The answer to that is definitely not. It is really impossible for us to say what is moving and what is sitting still. For example, consider your grandmother's house. Is it moving? You would probably say that it is not. However, suppose I were on the moon observing her house through a powerful telescope. In order to continue to observe her house, I would have to constantly change the direction in which my telescope is pointing. Why? Because relative to the moon, her house *is* moving. Thus, motion truly is relative. There is no way for us to point at something and say that it is moving. Relative to us (or some other observer) it might be moving, but relative to another observer, it might very well be sitting still. Thus, the best we can do is say that relative to *us*, the object is moving.

What an observer actually sees, then, is the difference between his velocity and the velocity of what he is observing. Let's go back to the situation we were just discussing. From your grandmother's point of view, her velocity was zero. You, on the other hand, were moving away from her in the car. The velocity she saw was the difference between her velocity (0) and your velocity. Thus, she observed you moving. Your father, however, was moving with the car and had exactly the same velocity (relative to your grandmother) that you did. The difference between his velocity and your velocity, then, was zero, and that's why from your father's viewpoint, you were not moving. See if you understand this concept by studying the following example and performing the "On Your Own" problem afterwards.

Illustrations from the MasterClips collection

EXAMPLE 1.5

A car and a truck are approaching each other on a 2-lane road (see diagram below). The speedometer in the car reads 56 mph, and the speedometer in the truck reads 45 mph. If you were standing at the side of the road watching this situation, what velocity would you observe for the car? What velocity would you observe for the truck? What velocity does the driver of the car observe for the truck? What velocity does the driver of the truck observe for the car?



What would you see? You are standing still, so as far as you are concerned, your velocity is zero. If we define motion to your right as positive, you see the car moving at 56 mph - 0 mph = 56 mph. Thus, <u>according to you, the car is moving to your right at 56 mph</u>. Since the truck is moving to your left, you see its velocity as -45 mph - 0 mph = -45 mph. As a result, <u>you see the truck traveling at 45 mph to your left</u>. The driver in the car, however, is already moving. As he looks at the truck, he has no idea what its speedometer reads. What he does see, however, is that the truck is approaching very quickly. As all observers do, he sees the difference between his velocity and the truck's velocity. Thus, the velocity he observes is -45 mph - 56 mph = -101 mph. According to our definition of positive and negative, this means that <u>the driver of the car observes the truck moving to your left at 101 mph</u>. Finally, the truck driver also observes the difference between the car's velocity and his velocity. Thus, the truck driver observes a velocity of 56 mph - (-45 mph) = 101 mph. The positive sign means that the motion is to your right. Thus, <u>the truck driver sees the car moving to your right at 101 mph</u>.

In the end, then, the velocity of the car and truck depend on the observer. As the stationary person in the example, you observed one set of velocities, while the drivers observed another. That's what I mean when I say that velocity is relative. It depends on the observer. As a point of mathematical clarification, when you are calculating the difference in velocities, always take the velocity of what is being observed minus the velocity of the observer. That way, your signs will always work out to the proper directions.

ON YOUR OWN

1.7 A boat is traveling up a river against the current. A boy on a raft is floating down the river with the current. They are both being observed by a fisherman sitting on the shore. The fisherman observes the boat traveling 15 m/sec up the river. He also notices that the boy and his raft have a velocity of 3 m/sec down the river. What is the velocity of the raft as observed by someone on the boat? What is the velocity of the boat as observed by the boy on the raft ?

Acceleration

We now come to the last concept we need to cover in this module: **acceleration**.

Acceleration - The time rate of change of an object's velocity

Does this definition sound similar to the one for velocity? It should. Just as velocity measures how an object's position varies with time, acceleration measures how an object's velocity changes with time. The mathematical definition of acceleration is as follows:

$$\mathbf{a} = \frac{\Delta\mathbf{v}}{\Delta t} \tag{1.3}$$

where "**a**" is the acceleration, "**v**" is the velocity, and "t" is time. Once again, since **a** and **v** are in boldfaced type, they are vector quantities.

What units are attached to acceleration? Well, we already know that velocity has the SI unit of m/sec. In order to get acceleration, you take the change in velocity (which still has units of m/sec) and divide by time (which has the SI unit of seconds). What happens when you take m/sec and divide by sec? You get m/sec^2 (meters per second squared). This is the SI unit for acceleration.

Since Equation (1.3) tells us that acceleration is a vector, we need to be sure we understand all of the implications of this fact. When you hear the term "acceleration" in everyday language, it means "speed up." For example, when a driver increases the velocity of a car, we say that the car accelerated. In physics, though, acceleration does not have to mean "speed up." It can also mean "slow down." After all, acceleration just tells us how the velocity of an object is changing. If the velocity is decreasing, then it is changing, and thus there is acceleration.

When we see acceleration, then, how will we know whether it is causing an increase in velocity (speeding the object up) or a decrease in velocity (slowing the object down)? Actually, it is quite simple. If the acceleration and velocity have opposite signs, the object is slowing down. If they have identical signs, the object is speeding up. Thus, if an object has a velocity of -3.2 m/sec and an acceleration of 0.1 m/sec^2, the object is slowing down. Alternatively, a velocity of 13.2 m/sec and an acceleration of 2.2 m/sec^2 mean that the object is speeding up. That's the vector nature of acceleration. If acceleration and velocity have the same direction, the acceleration is increasing the velocity. Alternatively, if the acceleration and velocity are pointed in opposite directions, the acceleration is decreasing the velocity. Perform the following experiment to help you understand what acceleration is all about.

EXPERIMENT 1.2
Measuring an Object's Acceleration

Note: A sample set of calculations is available in the solutions and tests guide. It is with the solutions to the practice problems.

Supplies:

- Safety goggles
- A stopwatch (A watch with a second hand will do.)
- A pile of books between 18 and 27 centimeters thick
- A wooden board, about 1 meter long (Any long, flat surface that you can prop up on one end will do. It needs to be as smooth as possible.)
- A pencil (Anything that you can use to mark the board will do.)
- A ball that will easily roll down the board
- A few extra books
- Masking tape or electrical tape
- An uncarpeted floor

1. Construct the same experimental setup that you had for Experiment 1.1. This time, however, use the tape to make a mark on the floor exactly 1.00 meter from the end of the board.
2. Hold the ball at the top of the board and release it. Do not start the stopwatch until the instant that the ball rolls off of the board and onto the floor. Stop the watch when the ball reaches the tape. In this way, you have measured the time it takes for the ball to roll one meter once it has left the end of the board.
3. Just as you did in Experiment 1.1, make this measurement five times and average the result.
4. Take that average and divide it into 1.00 m. This measures the average velocity of the ball once it rolls off of the board.
5. If you think about it, the ball rolls down the board because of gravity. We'll discuss that subject several times throughout this course, so I don't want to talk about gravity itself in depth at this time. Nevertheless, you should be aware that the reason the ball rolls down the board is that gravity is pulling it down. Since gravity is pulling down on the ball, the ball accelerates. It starts with a velocity of zero (because you held it still to begin with), and it rolls off of the board with a large velocity. Since velocity changed, by definition, there must have been acceleration. Gravity supplies that acceleration. Once the ball leaves the board, however, gravity can no longer accelerate it. Therefore, the ball rolls across the floor with a relatively constant velocity. Now, of course, the ball eventually slows down and stops because it either runs into something or because of *friction*, which we will explore in a later module. For the first meter after it rolls off the board, however, it is a reasonably good assumption that the ball rolls with a constant velocity, as long as the floor that you set the experiment on is not carpeted. Thus, the velocity that you measured is approximately the same as the velocity the ball had when it rolled off the end of the board.
6. Hold the ball at the top of the board again and release it. This time, start the watch as soon as you release the ball and stop it when the ball reaches the end of the board. Once again, make this measurement five times and average the result. Do not calculate any velocities. You are only measuring time in this portion of the experiment.
7. What does this measurement represent? Well, it represents the time it takes for the ball to roll down the board. What's so important about that? Think about it. The ball started (at the top of the board) with a velocity of zero and ended (at the bottom of the board) with the velocity that you measured in the first part of this experiment. Thus, it must have accelerated. When did that acceleration take place? When the object was on the board. Remember, the velocity of the ball

stayed constant once it rolled off of the board. This means that all of its acceleration took place while it was on the board. Therefore, we know the beginning velocity (0), and the ending velocity (the velocity that you measured in the first part of this experiment). If we subtract the former from the latter, we will get Δ**v**, the change in velocity while the ball was on the board. The time that you just measured is the time interval over which the ball stayed on the board, or Δt. Take your value for Δ**v** and divide it by Δt, and you get the acceleration that the ball experienced!

8. Add 6-9 more centimeters of books to the book pile so that the board tilts more steeply. Repeat the entire experiment, so that you get a new value for acceleration.
9. Add another 6-9 cm worth of books to the pile and repeat the experiment one more time to get yet another value for the ball's acceleration.
10. Clean up your mess.

Now that you have completed the experiment, compare the three accelerations that you measured. The first one should be the smallest, the second one should be larger, and the third one should be the largest. That should not surprise you. As you increase the tilt of the board, gravity can pull the ball along the surface of the board more effectively. As a result, the ball's acceleration increases. This makes the ball travel along the board more quickly so that it has a greater velocity when it reaches the end of the board. That's what you saw in the experiment.

That conclusion was not the major goal of the experiment, however. The major goal was to show you how to measure an object's acceleration. You measured its initial velocity (0), its final velocity (the velocity at the end of the board), and the time it took for that change in velocity to occur. By taking the change in velocity and dividing by the time over which the change occurred, you got the acceleration. The fact that your measurement increased as the tilt of the board increased was simply an indication that you did, indeed, measure the ball's acceleration.

So we see that acceleration is the agent by which velocity change occurs. Study the following examples and solve the "On Your Own" problems that appear afterward so that you are sure to have a firm grasp of the concept of acceleration.

EXAMPLE 1.6

A car is moving with a velocity of 25 m/sec to the east. The driver suddenly sees a deer in the middle of the road and slams on the brakes. The car comes to a halt in 2.1 seconds. What was the car's acceleration?

This problem is a straightforward application of Equation (1.3). The problem says that the car starts with a velocity of 25 m/sec east and ends up stopping (v = 0). Thus, we can subtract the initial velocity from the final velocity to get Δ**v**:

$$\Delta \mathbf{v} = \mathbf{v}_{\text{final}} - \mathbf{v}_{\text{initial}} = 0 \text{ m/sec} - 25 \text{ m/sec} = -25 \text{ m/sec}$$

The problem also gives us time, so to calculate the acceleration, all we have to do is plug these numbers into Equation (1.3):

$$\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t}$$

$$\mathbf{a} = \frac{-25\ \frac{m}{sec}}{2.1\ sec} = -12\ \frac{m}{sec^2}$$

What does the negative mean? Well, since we made the initial velocity positive, that defined motion to the east as positive. The fact that the acceleration is negative means that the acceleration is pointed in the *opposite* direction. Thus, the car's acceleration was 12 m/sec^2 to the west. Since the velocity and acceleration are pointed in different directions, the car was slowing down. Of course, you already know that the car was slowing down, as the driver was trying to stop. However, this problem illustrates what I have already discussed: when the acceleration and velocity are pointed in opposite directions, the speed will decrease.

In the next module, we will learn that when objects are dropped, they fall straight down with an acceleration of 9.8 m/sec^2. If a ball is dropped with no initial velocity, how long would it take to accelerate to a downward velocity of 11.0 m/sec?

This problem tells us acceleration and the change in velocity and asks us to calculate the time over which the change occurred. The velocity starts at 0 m/sec and ends at 11.0 m/sec. Thus, we can calculate $\Delta \mathbf{v}$:

$$\Delta \mathbf{v} = \mathbf{v}_{final} - \mathbf{v}_{initial} = 11.0\ m/sec - 0\ m/sec = 11.0\ m/sec$$

Before I go on, I want to make a quick point about significant figures. This equation might pose a dilemma for you when trying to determine how many significant figures $\Delta \mathbf{v}$ should have. After all, how many significant figures does 0 m/sec have? Well, when you read a statement like "no initial velocity" or "it comes to a halt," you have to assume that the object is not moving at all. Thus, you must assume that its velocity is *exactly* 0.00000000… m/sec. As a result, it is infinitely precise and has an infinite number of significant figures. Thus, the precision with which we report our answer depends only on the *other* numbers in the problem, not the zero. That's why I reported my answer to the tenths place, because the other number in the problem has its last significant figure in the tenths place. Now please understand that the ball probably doesn't have *exactly* zero velocity. The person dropping the ball probably cannot hold her hand perfectly still, for example. Thus, the ball probably has some small initial velocity. However, compared to our other measurements, the size of that velocity is most likely insignificant, so it is safe to assume that a velocity of zero is exact, at least as far as we are concerned.

Now that we have acceleration and $\Delta \mathbf{v}$, we can use Equation (1.3) to solve for time:

$$\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t}$$

$$9.8\ \frac{m}{sec^2} = \frac{11.0\ \frac{m}{sec}}{\Delta t}$$

$$\Delta t = \frac{11.0\ \frac{\cancel{m}}{\cancel{sec}}}{9.8\ \frac{\cancel{m}}{sec^{\cancel{2}}}} = 1.1\ sec$$

Notice how the units work out here. The meters cancel, and the seconds in the velocity unit cancels the square in "sec^2" of the acceleration unit, leaving the unit as seconds. That's good, since we are solving for time. Thus, it takes the ball 1.1 seconds to accelerate to a velocity of 11.0 m/sec downwards. Now 11.0 m/sec is about the same as 25 mph, so things that fall speed up quickly!

ON YOUR OWN

1.8 A sprinter starts from rest and, in 3.4 seconds, is traveling with a velocity of 16 m/sec east. What is the sprinter's acceleration?

1.9 A race car accelerates at -7.2 m/sec^2 when the brakes are applied. If it takes 3.1 seconds to stop the car when the brakes are applied, how fast was the car originally going?

1.10 In Experiment 1.2, we made an assumption that the velocity of the ball was constant while it was rolling from the end of the board to the tape. However, we know that this assumption is wrong to some extent, because we know that given enough time, the ball will eventually stop rolling. Describe a way that we could use the same experimental setup to evaluate the validity of this assumption.

Average and Instantaneous Acceleration

Since the equations for velocity and acceleration are similar, you might expect that acceleration, like velocity, can be defined as average or as instantaneous. Just like velocity, when the time interval is large, the acceleration is an average. When the time interval is infinitely short, however, the acceleration is instantaneous. Just like velocity, the only real way to determine instantaneous acceleration is by studying graphs.

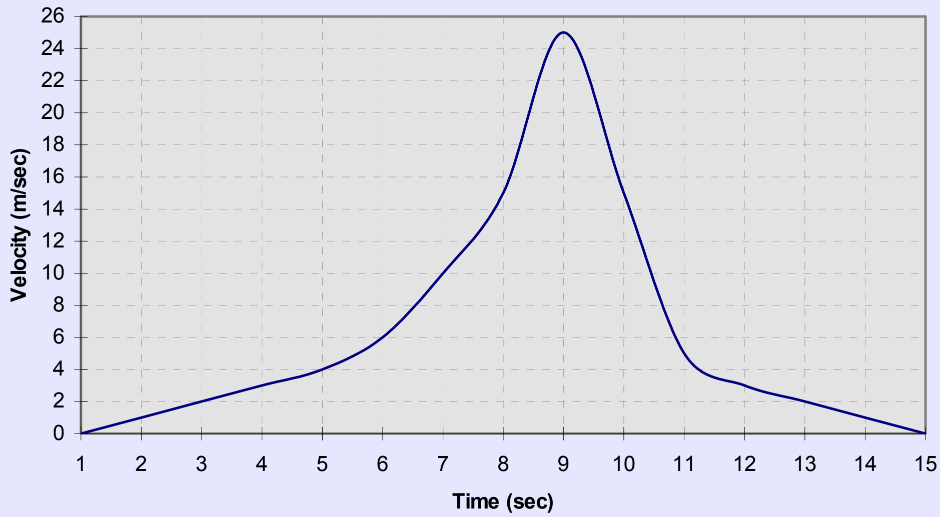
What kinds of graphs will we study in this case, however? Well, since acceleration tells us how velocity changes with time, we should examine velocity-versus-time graphs. If we plot velocity on the y-axis and time on the x-axis, the slope of the curve will be the acceleration.

The slope of a velocity-versus-time curve is the acceleration.

Since the methods for studying velocity-versus-time curves are identical to the ones we used to analyze position-versus-time curves, I will not explain them all over again. Instead, study the next example and solve the "On Your Own" problems that follow to make sure you can analyze these graphs as well.

EXAMPLE 1.7

A race car's motion is given by the following graph:



Over what time interval is the car speeding up?

The car speeds up when acceleration and velocity have the same sign. According to the graph, velocity is always positive. This means that in order to be speeding up, the acceleration must also be positive. Thus, the car is speeding up when the curve is rising. This occurs during the time interval of <u>1.0 to 9.0 seconds</u>. The car is slowing down from 9.0 to 15.0 seconds.

When is the car's acceleration zero?

The slope of a curve is zero when the curve is flat. This happens briefly at <u>9.0 seconds</u>.

What is the instantaneous acceleration of the car at 3.0 seconds?

The curve looks like a straight line from 1.0 to 4.0 seconds. Thus, the slope of the curve at any point during that time interval is the same as the average slope. At 1.0 second, the velocity is 0.0 m/sec. At 4.0 seconds, the velocity is 3.0. The average slope, then, is:

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{3.0\ \frac{\text{m}}{\text{sec}} - 0.0\ \frac{\text{m}}{\text{sec}}}{4.0\ \text{sec} - 1.0\ \text{sec}} = 1.0\ \frac{\text{m}}{\text{sec}^2}$$

This slope is the same throughout that entire time interval, so at 3.0 seconds, the acceleration is <u>1.0 m/sec^2</u>.

ON YOUR OWN

Consider an object whose motion is described by the following graph:

1.11 During what time intervals is the object's speed increasing?

1.12 When is the object's acceleration zero?

Before we finish this module, I need to make two points. First, there is one special property of a velocity-versus-time curve. The area under such a curve represents the object's displacement. Thus, if I could take the velocity-versus-time curve above and somehow calculate how much area exists under the line, I would be able to determine the final displacement of the object. Now, of course, you have no way of doing this, so you don't have to worry. I won't ask you any questions about this. It turns out, however, that the mathematical field of calculus is devoted to two things: calculating the slope of curves and *the area under curves*. Thus, when you learn calculus, you will learn another way to analyze these graphs.

The last point I need to make is rather important. If you solved "On Your Own" problem 1.12 correctly, you found that there were two times that the object had zero acceleration: approximately 6.0 seconds and 11.8 seconds. What were the object's velocities at those two times? They were 40 m/sec and 102 m/sec, respectively. Note that *although the acceleration was zero at these times, the velocity was not*. This is an important point and cannot be overemphasized. It is very tempting to say that velocity is zero when acceleration is zero. Although that is indeed possible, it is *not necessarily true*.

The converse of this statement is just as true and just as important. In the "On Your Own" section above, what was the velocity of the object at 16 seconds? It was zero. Was the acceleration zero? No, it was negative. We see, then, that acceleration does not have to be zero when the velocity is zero. Acceleration is the *change* in velocity. Thus, it is very possible for one to be zero and the other to be non-zero.

If velocity is zero, acceleration does not have to be zero.
If acceleration is zero, velocity does not have to be zero.

Plant this fact in your head, or you will be really lost in the next module!

ANSWERS TO THE "ON YOUR OWN" PROBLEMS

1.1 The total distance is easy to calculate. The ant crawled 15.2 centimeters in one direction and 3.8 centimeters in the other. The total distance then, is simply:

Total Distance = 15.2 cm + 3.8 cm = 19.0 cm

Now remember, we have to take significant figures into account when determining the answer. Since we are adding two numbers, we use the rule of addition and subtraction, which tells us to report our answer to the same precision as the least precise number in the problem. Both 15.2 cm and 3.8 cm have their last significant figure in the tenths place. Thus, I must report my answer to the tenths place. That's why the answer is 19.0 cm. Please note that 19 cm is not really correct. It is not precise enough. The measurements given are precise enough for us to report the digit in the tenths place, even if it happens to be zero. In the same way, 19.00 cm would also not be correct, as it is too precise for the measurements given.

Calculating the displacement is a bit more difficult. To do this, we must first define direction. I will say that motion from the anthill to the bread results in positive displacement while motion from the bread to the anthill results in negative displacement. Thus, the ant first had a displacement of +15.2 cm and then a displacement of -3.8 cm. The total displacement, then, is:

Total Displacement = 15.2 cm + -3.8 cm = 11.4 cm

Once again, since both of the measured distances have their last significant figure in the tenths place, the answer must be reported to the tenths place. This is a positive displacement, which means that the ant is 11.4 cm away from the anthill, in the direction of the bread.

Note that saying 11.4 cm isn't good enough. With the opposite definition of positive and negative displacement, another person would have gotten -11.4 cm. Both answers would be correct, depending on the definition of direction. Thus, we must give the answer in relation to the points in the problem, so that the answer is independent of our definition of positive and negative direction.

1.2 In this problem, we are asked to calculate velocity, so we will be using Equation (1.1). Once again, we are dealing with vector quantities here, so we must define direction. I will call motion down the street positive motion and motion up the street negative. The first part of the question asks us to calculate the mail carrier's velocity while she travels down the street. Well, during that time, her displacement was 3.00×10^2 meters. It took her 332 seconds to travel down the street, so Equation (1.1) becomes**:**

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{3.00 \times 10^2 \text{ m}}{332 \text{ sec}} = 0.904 \frac{\text{m}}{\text{sec}}$$

We could therefore say that her velocity was 0.904 m/sec down the street. The second part of the question asks us to calculate her velocity as she is traveling up the street. During that time, her displacement was negative, so Equation (1.1) becomes:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{-208 \text{ m}}{2.30 \times 10^2 \text{ sec}} = -0.904 \frac{\text{m}}{\text{sec}}$$

Thus, we could say that her velocity was 0.904 m/sec up the street. Finally, the problem asks us to determine her velocity over the entire trip. Well, in order to determine velocity, we must first determine displacement. The mail carrier's total displacement was 3.00×10^2 m + -208 m = 92 m. The total time it took to achieve that displacement was 332 sec + 2.30×10^2 sec = 562 sec. Equation (1.1), then, becomes:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{92\ \text{m}}{562\ \text{sec}} = 0.16\ \frac{\text{m}}{\text{sec}}$$

Since the velocity is positive, we know that even though the mail carrier traveled in both directions, her overall velocity was 0.16 m/sec down the street.

1.3 The problem gives us a speed and a direction. This means that the 15 m/sec is actually a velocity. In addition, we are told how far the boat travels (34.1 km). If we consider the place the boat started as our point of reference, then this distance is actually the displacement during the boat ride ($\Delta \mathbf{x}$). The problem, however, is that the units do not match. Velocity is in m/sec while displacement is in km. We need to gets these units into agreement, so we need to convert km into m:

$$\frac{34.1\ \cancel{\text{km}}}{1} \times \frac{1{,}000\ \text{m}}{1\ \cancel{\text{km}}} = 3.41 \times 10^4\ \text{m}$$

Now we can substitute into Equation (1.1), use algebra to rearrange the equation, and solve for time:

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

$$15\ \frac{\text{m}}{\text{sec}} = \frac{3.41 \times 10^4\ \text{m}}{\Delta t}$$

$$\Delta t = \frac{3.41 \times 10^4\ \cancel{\text{m}}}{15\ \frac{\cancel{\text{m}}}{\text{sec}}} = 2.3 \times 10^3\ \text{sec}$$

Thus, the boat ride took 2.3×10^3 seconds, or 38 minutes.

1.4 The slope of the curve is steeper at 3.5 seconds than at 8.5 seconds, so the object is moving faster at 3.5 seconds.

1.5 The slope changes from positive to negative at 4.3 seconds. This represents one direction change. The slope changes from negative to positive at 8.0 seconds, representing the second direction change. It changes from positive to negative at 9.0 seconds and then again from negative back to positive at about 10.2 seconds. These represent the third and fourth direction changes. Finally, at 11.0 seconds, the slope changes from positive to negative. This is the fifth (and last) direction change. Thus, the object changed directions five times.

1.6 During the interval of 0.0 to 2.0 seconds, the curve looks like a straight line. Thus, the slope at any point along that part of the curve is the same. We can therefore calculate the average velocity from 0.0 to 2.0 seconds and, since the velocity stays the same throughout that entire time interval, it will also be the instantaneous velocity at any time during that interval, including 1.0 seconds. To read from the graph, we have to realize that it is marked off in seconds and two-meter intervals, so by estimating in between the marks, we can report our positions and times to the tenths place.

The position at 0.0 seconds is 0.0 meters according to the graph. At 2.0 seconds, the displacement is 2.0 meters. The average velocity, then, is:

$$\text{slope} = \mathbf{v} = \frac{\text{rise}}{\text{run}} = \frac{2.0\text{ m} - 0.0\text{ m}}{2.0\text{ sec} - 0.0\text{ sec}} = 1.0\ \frac{\text{m}}{\text{sec}}$$

This means that the instantaneous velocity at 1.0 second is also <u>1.0 m/sec</u>.

1.7 We have the velocities relative to the fisherman, so we can use them to determine the velocities of the raft and the boat relative to each other. We will say that motion up the river is positive and motion down the river is negative. Thus, the boat is traveling at 15 m/sec, and the raft is traveling at -3 m/sec.

To determine the velocity of an object relative to another, we take the velocity of the thing being observed and subtract from it the velocity of the observer. Therefore, a person on the boat observes the raft moving at -3 m/sec - 15 m/sec = -18 m/sec. Since negative means motion down the river, <u>the people on the boat observe the raft moving 18 m/sec down the river</u>. The boy on the raft, however, observes the boat moving at a velocity of 15 m/sec - (-3 m/sec) = 18 m/sec. Since positive means motion up the river, <u>the boy observes the boat moving 18 m/sec up the river</u>. Please note that I could have defined motion up the river as negative and motion down the river as positive. If I did that, the answers would end up with different signs, but once I translated the signs into "up the river" and "down the river," the answers would end up the same.

1.8 This problem is a straightforward application of Equation (1.3). The problem says that the sprinter starts from rest ($\mathbf{v}$ = 0) and sprints to a velocity of 16 m/sec. Thus, we can subtract the initial velocity from the final velocity to get $\Delta\mathbf{v}$:

$$\Delta\mathbf{v} = \mathbf{v}_{\text{final}} - \mathbf{v}_{\text{initial}} = 16\text{ m/sec} - 0\text{ m/sec} = 16\text{ m/sec}$$

The problem also gives us time, so to calculate the acceleration, all we have to do is plug these numbers into Equation (1.3):

$$\mathbf{a} = \frac{\Delta\mathbf{v}}{\Delta t}$$

$$\mathbf{a} = \frac{16\ \frac{\text{m}}{\text{sec}}}{3.4\text{ sec}} = 4.7\ \frac{\text{m}}{\text{sec}^2}$$

Since acceleration and velocity have the same signs, we know that they are pointed in the same direction. Therefore, the sprinter was speeding up, and the sprinter's acceleration was <u>4.7 m/sec^2 east</u>.

1.9 This problem tells us acceleration, time, and final velocity and asks us to calculate the initial velocity. We can do this by calculating $\Delta\mathbf{v}$, using Equation (1.3):

$$\mathbf{a} = \frac{\Delta\mathbf{v}}{\Delta t}$$

$$-7.2\ \frac{\text{m}}{\text{sec}^2} = \frac{\Delta\mathbf{v}}{3.1\,\text{sec}}$$

$$\Delta\mathbf{v} = -7.2\ \frac{\text{m}}{\text{sec}^{\cancel{2}}} \times 3.1\ \cancel{\text{sec}} = -22\ \frac{\text{m}}{\text{sec}}$$

Now that we have $\Delta\mathbf{v}$, we can use the definition of $\Delta\mathbf{v}$ to solve for the initial velocity:

$$\Delta\mathbf{v} = \mathbf{v}_{\text{final}} - \mathbf{v}_{\text{initial}}$$

$$-22\ \text{m/sec} = 0\ \text{m/sec} - \mathbf{v}_{\text{initial}}$$

$$\mathbf{v}_{\text{initial}} = 22\ \text{m/sec}$$

Thus, the car was originally traveling at 22 m/sec. Notice that the velocity and acceleration have different signs. They should, since the car slowed down!

1.10 To test the assumption, put another piece of tape at 0.500 meters from the edge of the board. Then, measure the average velocity of the ball as it travels from the end of the board to the first piece of tape. Next, measure the average velocity of the ball as it travels from the first piece of tape to the second piece of tape. Compare the two velocities. If the assumption is good, the velocities should be roughly equal, indicating that the ball did not slow down significantly between the first half of its trip and the second half of its trip. However, if the second velocity is significantly lower than the first, then the ball *did* slow down considerably over the course of 1 meter, and the assumption was not valid.

1.11 Be very careful solving this one. Remember, the object will speed up whenever velocity and acceleration have the same signs. From the time interval of 6.0 seconds to 11.8 seconds, the velocity is positive and the acceleration (slope) is positive. Thus, the object speeds up in that interval. You might be tempted to say that this is the only interval in which the car speeds up, but you would be wrong. From 16.0 seconds to 20.0 seconds, the velocity and acceleration are both negative. Thus, the object is speeding up then as well. Therefore, there are two time intervals during which the object speeds up, 6.0 - 11.8 seconds and 16.0 - 20.0 seconds. (Your numbers may be slightly different from mine, since you are reading from a graph. That's fine.)

1.12 The acceleration is zero wherever the curve is flat. That happens at about 6.0 seconds and 11.8 seconds. (Your numbers may be slightly different from mine, since you are reading from a graph. That's fine.)

REVIEW QUESTIONS

1. What is the main difference between a scalar quantity and a vector quantity?

2. On a physics test, the first question asks the students to calculate the acceleration of an object under certain conditions. Two students answer this question with the same number, but the first student's answer is positive while the second student's answer is negative. The teacher says that they both got the problem 100% correct. How is this possible?

3. Which is a vector quantity: speed or velocity?

4. What is the main difference between instantaneous and average velocity?

5. What physical quantity is represented by the slope of a position-versus-time graph?

6. What do physicists mean when they say that velocity is "relative?"

7. You are reading through someone else's laboratory notebook, and you notice a number written down: 12.3 m/sec^2. Even though it is not labeled, you should immediately be able to tell what physical quantity the experimenter measured. What is it?

8. Another experiment in the same laboratory notebook says that an object has a 1.4 m/sec^2 acceleration when it has a -12.6 m/sec velocity. At that instant in time, is the object speeding up or slowing down?

9. What kinds of graphs do you study if you are interested in learning about acceleration?

10. An object's velocity is zero. Does this mean its acceleration is zero? Why or why not?

PRACTICE PROBLEMS

1. A delivery truck travels down a straight highway for 35.4 km to make a delivery. On the way back, the truck has engine trouble, and the driver is forced to stop and pull off the road after traveling only 13.2 km back towards its place of business. How much distance did the driver cover? What is his final displacement?

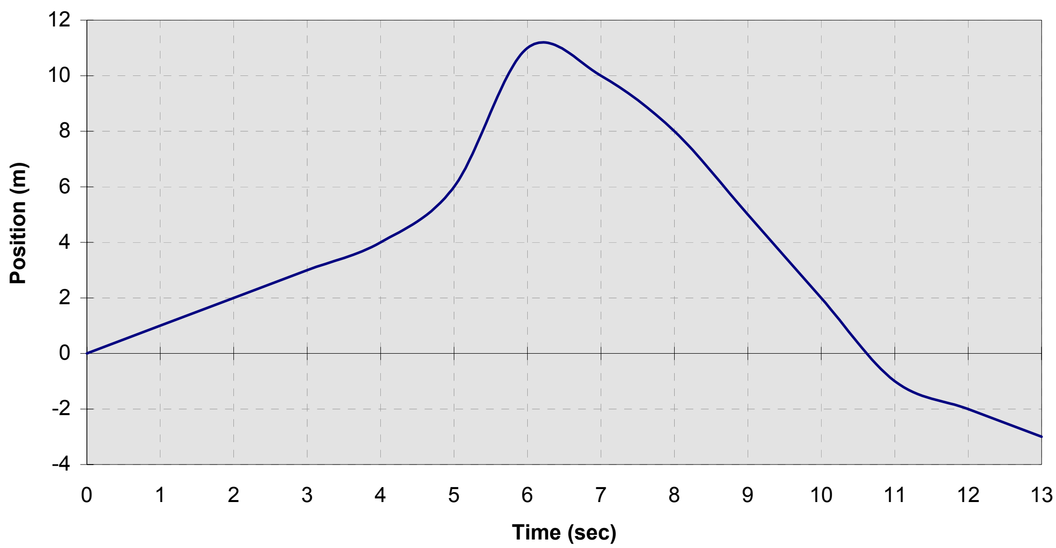
2. If the driver in the above problem took 21.1 minutes to reach the delivery point and broke down 7.5 minutes into the return trip, what was the average speed? What was the driver's average velocity?

3. A plane flies straight for 672.1 km and then turns around and heads back. The plane then lands at an airport that is only 321.9 km away from where the pilot turned around. If the plane's average velocity over the entire trip was 42 m/sec, how much time did the entire trip take?

4. An athlete runs 1600.0 meters down a straight road. Over the first 800.0 meters, the runner's average velocity is 6.50 m/sec. Over the remaining 800.0 meters, his average velocity is 4.30 m/sec. What is the runner's average velocity over the entire race? [Be careful on this one. Remember what Equation (1.1) tells you.]

<u>Questions 5 and 6 refer to the figure below:</u>

A car's motion is described by the following position-versus-time curve:



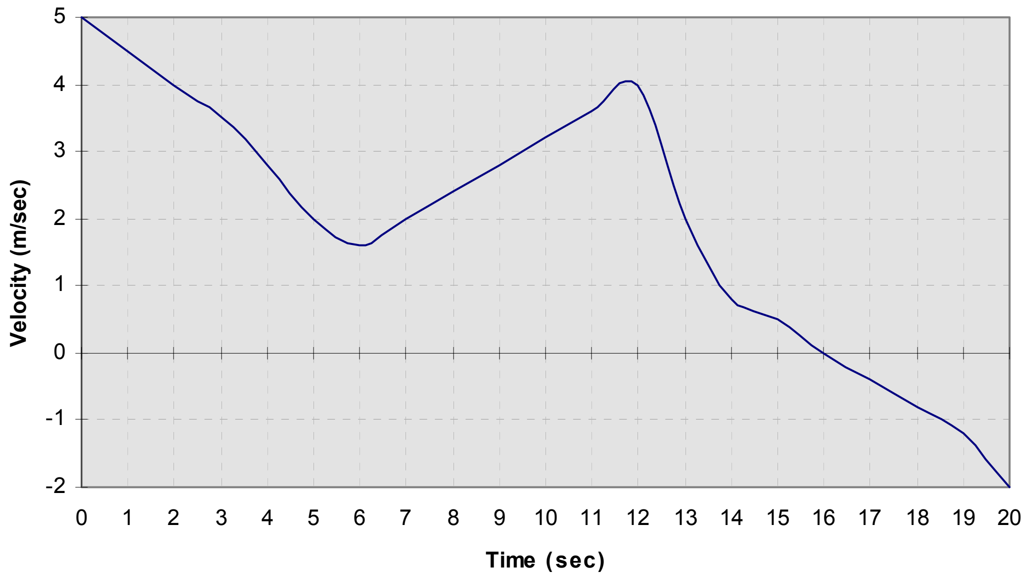
5. At approximately what time does the car change its direction?

6. Over what time interval is the car moving the fastest?

7. A train is traveling with an initial velocity of 20.1 m/sec. If the brakes can apply a maximum acceleration of -0.0500 m/sec^2, how long will it take the train to stop?

Questions 8 - 10 refer to the figure below:

A runner's motion is described by the following velocity-versus-time graph:



8. Over what time intervals is the runner slowing down?

9. What is the runner's acceleration at 6.0 seconds?

10. What is the runner's acceleration at 1.0 seconds?