

Exploring Creation With Physics

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Introductory Remarks

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

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Ernest Rutherford



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

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

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

Of course, if you are going to attempt to study and understand the details of how things interact in nature, you will have to do a lot of observation and experimentation. One of the most important

aspects of observation and experimentation is measurement; thus, you will be making and using a lot of measurements in this course. As a result, you need to become very comfortable with the process of making measurements and the language that revolves around those measurements. You must also be comfortable with using those measurements in mathematical equations and making sure that you report the results of the equations with a precision that reflects the precision of the original measurements.

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

The Metric System

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

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

The Factor-Label Method

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

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

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

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 $1.2 \text{ m} + 3.4 \text{ kg}$ 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.

Image in the public domain

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)

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 Δv , 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 Δv 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 Δv :

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

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

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

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

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/sec² 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/sec². 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 $\Delta \mathbf{v}$:

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

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:

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

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

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

Notice how the units work out here. The meters cancel, and the seconds in the velocity unit cancels the square in “sec²” 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.

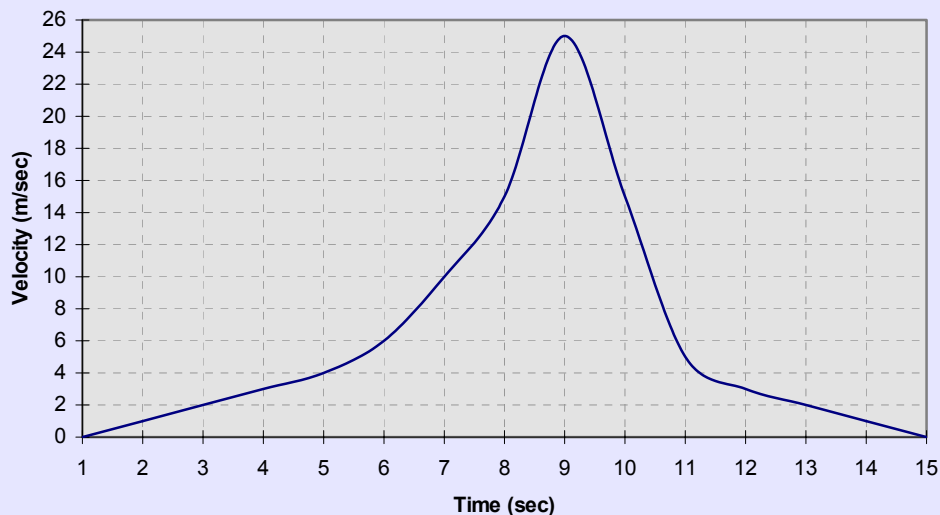
What kinds of graphs will we study in this case, however? Well, since acceleration tells us how velocity changes with time, we should examine velocity-versus-time graphs. If we plot velocity on the y-axis and time on the x-axis, the slope of the curve will be the acceleration.

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 1.0 to 9.0 seconds. 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 9.0 seconds.

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

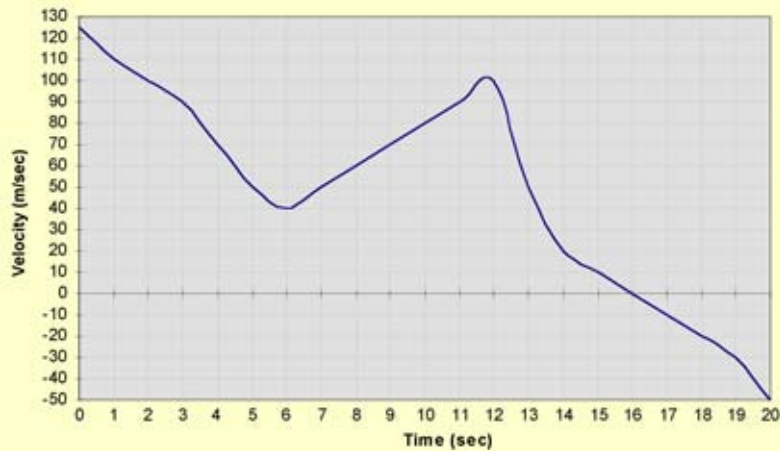
The curve looks like a straight line from 1.0 to 4.0 seconds. Thus, the slope of the curve at any point during that time interval is the same as the average slope. At 1.0 second, the velocity is 0.0 m/sec. At 4.0 seconds, the velocity is 3.0. The average slope, then, is:

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

This slope is the same throughout that entire time interval, so at 3.0 seconds, the acceleration is 1.0 m/sec².

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:

$$\text{Total Distance} = 15.2 \text{ cm} + 3.8 \text{ cm} = 19.0 \text{ cm}$$

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:

$$\text{Total Displacement} = 15.2 \text{ cm} + -3.8 \text{ cm} = 11.4 \text{ cm}$$

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 $3.00 \times 10^2 \text{ m} + -208 \text{ m} = 92 \text{ m}$. The total time it took to achieve that displacement was $332 \text{ sec} + 2.30 \times 10^2 \text{ sec} = 562 \text{ sec}$. 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 get 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 1.0 m/sec.

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 $-3 \text{ m/sec} - 15 \text{ m/sec} = -18 \text{ m/sec}$. Since negative means motion down the river, the people on the boat observe the raft moving 18 m/sec down the river. The boy on the raft, however, observes the boat moving at a velocity of $15 \text{ m/sec} - (-3 \text{ m/sec}) = 18 \text{ m/sec}$. Since positive means motion up the river, the boy observes the boat moving 18 m/sec up the river. 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 4.7 m/sec² east.

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 Δv , using Equation (1.3):

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

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

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

Now that we have Δv , we can use the definition of Δv 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

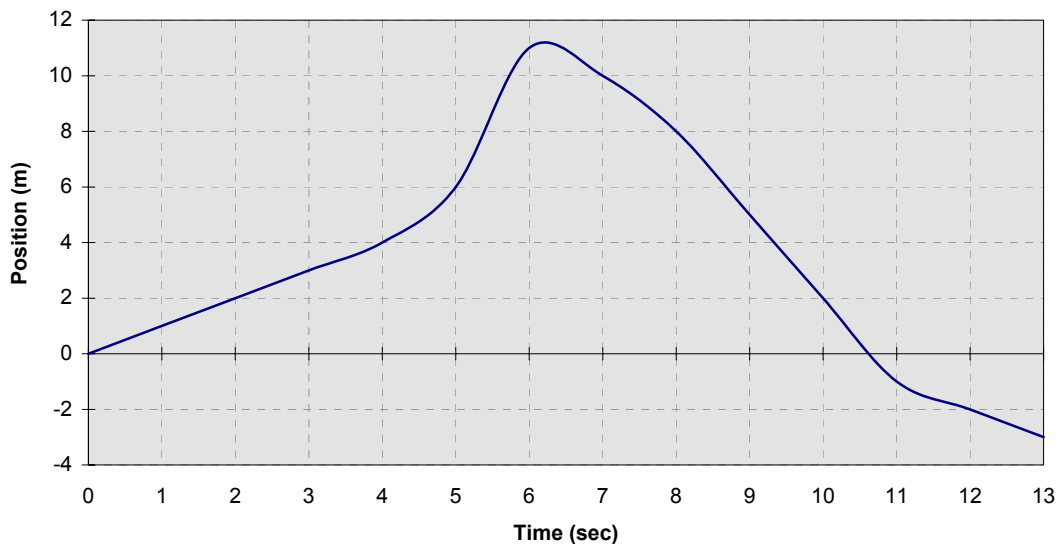
1. What is the main difference between a scalar quantity and a vector quantity?
2. On a physics test, the first question asks the students to calculate the acceleration of an object under certain conditions. Two students answer this question with the same number, but the first student's answer is positive 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.]

Questions 5 and 6 refer to the figure below:

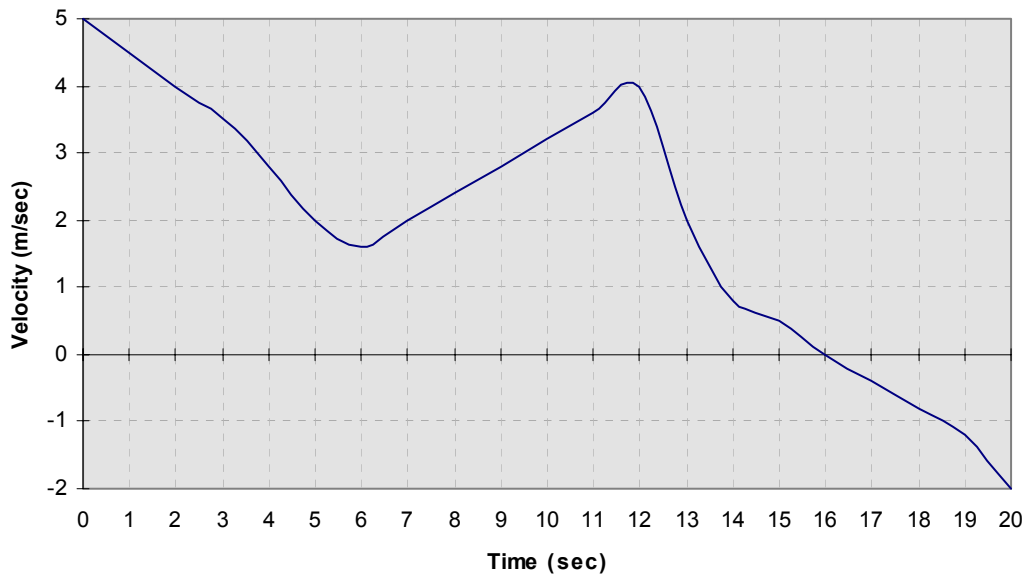
A car's motion is described by the following position-versus-time curve:



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?