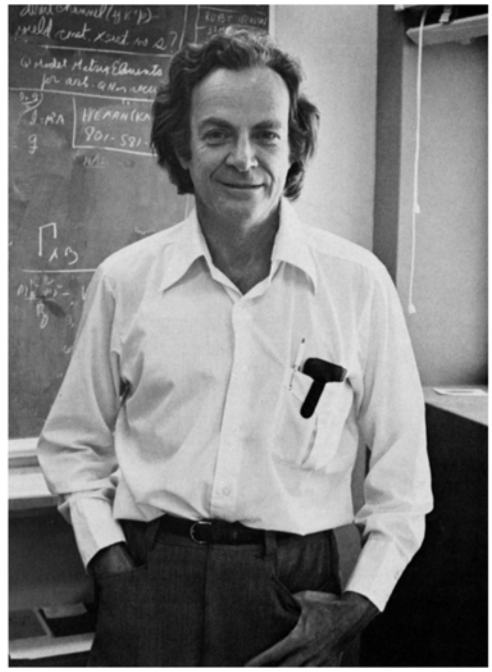
Chapter 1: Let's Move!

Introduction

If you haven't yet read the introduction to this book (pp. iii-v), please do so now.

Physics is fundamental to all of the sciences because it is the study of matter and energy and how they interact with one another. One of the most important physicists of the 20th century, Dr. Richard Feynman, put it this way:

> Physics is the most fundamental and all-inclusive of the sciences, and has had a profound effect on all scientific development. In fact, physics is the present-day equivalent of what used to be called *natural philosophy*, from which most of our modern sciences arose.
> (https://www.feynmanlectures.caltech.edu/I_03.html)



Dr. Richard Feynman in 1988

Since physics is such a fundamental science, the laws of physics govern everything that God has created. As a result, the more physics you learn, the better you understand God's creation.

In addition, physics is an inherently mathematical subject. In fact, that's why you are taking physics so late in your high school career. In order to properly understand physics, you need to be well-versed in algebra and geometry. You especially need to know three basic trigonometric functions (sine, cosine, and tangent) and understand how they relate to a right triangle. If you don't have that level of mathematics preparation, you should not attempt this course.

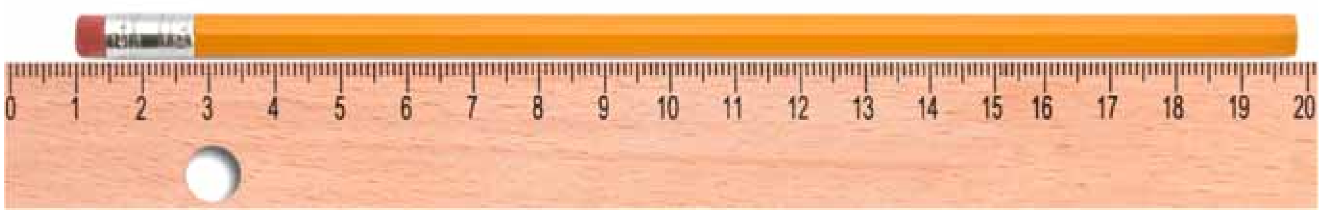
Let's Make Sure You Are Ready

In physics, we make a lot of measurements, and there are some specific concepts that you need to understand to make measurements properly and deal with those measurements in mathematical equations. If you had a good chemistry course, you already know them, but before we get started on the "meat" of this course, I want to review them here.

When you make a measurement, you must list the **units** you used. For example, if you want to measure the length of something, you could measure it in **inches, feet, yards**, etc. Those are often called the **English units** of length. You could also measure it in **centimeters**, **meters**, or **kilometers**, which are **metric units**. We will concentrate on metric units, so you need to know the base metric units (meters, grams, and seconds) and how they are modified with the prefixes "centi," "milli," and "kilo." We will use English units occasionally, so you also need to be able to recognize them. You should also understand that the units indicate what was measured. A measurement of 15.0 kilograms, for example, is a mass measurement because the base metric unit for mass is the gram, and a kilogram means 1,000 grams.

There is also a standard set of metric units that are used in the sciences. They are called **SI units**, where "SI" stands for "Système International." You should already know that the SI unit for mass is the **kilogram** (**kg**), the SI unit of length is the **meter** (**m**), and the SI unit for time is the **second** (**s**). You will learn many other SI units in this course.

When making measurements, you also need to report your answers to the proper precision, which is determined by the measuring device you are using. Consider, for example, measuring the length of this pencil with a metric ruler:



As you should already know, you never start the measurement at the end of the ruler, since it gets damaged over time. Thus, you line up the "1 cm" mark with the beginning of the pencil, which means you have to subtract one from the number you find at the end of the pencil. Since the numbers represent centimeters, and since there are 10 lines between each number, you know the ruler is marked off in tenths of a cm. As you should already know, you can estimate between the lines to get to the next decimal place, so this pencil is 18.82 cm long. Its length is not 19 cm or 18.8 cm. It is 18.82 cm. You might say 18.81 cm, 18.83 cm, or 18.84 cm because your estimation might be a bit different from mine. That's fine. If the pencil had lined up perfectly with the eighth mark, its length would be 18.80 cm. Since you are capable of reading the ruler to the hundredths of a cm because of your estimation, you must list the value of the hundredths place, even if it is zero.

Reporting your measurements with the proper precision is important, since that affects the **significant figures** contained in the measurement. A significant figure is one that was actually measured. When you are reading measurements, you can identify the significant figures this way:

1. **All non-zero figures (1, 2, 3, 4, 5, 6, 7, 8, and 9) are significant.**
2. **A zero is significant if it is between two significant figures.**
3. **A zero is also significant if it's at the end of the number *and* to the right of the decimal point.**

In the measurement 18.80 cm, then, all of the figures are significant. In a measurement like 0.0180 cm, however, the first two zeroes are not significant, but the "1," "8," and final "0" are.

Significant figures are important because they tell you how to round your answer when you are doing mathematics with measurements. The rules depend on whether you are doing addition/subtraction or multiplication/division.

When adding and subtracting measurements, you must report your answer to the same precision (decimal place) as the least precise number in the problem.

When multiplying and dividing measurements, you must report your answer with the same number of significant figures as the measurement which has the fewest.

Here are examples of how this works:

Example 1.1

What is the proper answer when a measurement of 15.423 cm is subtracted from 102 cm?

First, we can just subtract the two measurements:

$$102 \text{ cm} - 15.423 \text{ cm} = 86.577 \text{ cm}$$

However, because 102 cm has its last significant figure in the ones place, it is less precise than 15.423, which has its last significant figure in the thousandths place. As a result, 102 cm limits the precision of our answer to the ones place, so the proper answer is 87 cm. That has the same precision as 102, because they each have their last significant figure in the ones place. Also, note that we had to round up, because the first number we dropped was a "5."

What is the proper answer when a measurement of 15.423 cm is divided by 102 cm?

First, we can just divide the two measurements:

$$15.423 \text{ cm} \div 102 \text{ cm} = 0.151205882353$$

Depending on your calculator (yes, you should use a calculator in this course), your answer might have even more digits in it. That's fine, since the answer above already has far too many! The measurement of 15.423 cm has five significant figures, while the measurement 102 cm has three. Since the lowest number of significant figures is three, the answer can have only three. The answer, therefore, is 0.151. Remember that first zero is not significant, as it doesn't meet either condition for a zero being significant.

One other thing to notice is how the units work in a mathematical equation. You should already know that they act like variables in algebraic equations. Since $2x + 3x = 5x$, you can say 2 cm + 3 cm = 5 cm. Since $4x \div 2x = 2$ (the x's cancel), you can say 4 cm ÷ 2 cm = 2, because the cm's cancel.

You should also be familiar with **scientific notation**, especially as it relates to significant figures. Suppose you are computing the area of a field and measure it to be 5.00 m wide and 90.0 meters long. What is the area? When you multiply 5.00 m · 90.0 m, you get 450 m^2, but since 5.00 and 90.0 both have three significant figures, your answer must be reported to three significant figures. However, 450 has only two significant figures. The only way to properly report your answer is 4.50×10^2 m^2, since being both at the end of the number and to the right of the decimal place makes that last zero significant.

Finally, you need to be able to use the **factor-label method** to convert units. It's not enough just to convert units. You must be able to use this specific method, since it is a common tool in the sciences. To remind you, here is an example:

Example 1.2

An Olympic pool is 50.0 meters in length. How long is that in kilometers?

In order to do a conversion, we need a conversion relationship. The prefix "kilo" means "1,000," so we just write "1 km =" and then replace the prefix with its meaning:

$$1 \text{ km} = 1{,}000 \text{ m}$$

Notice how the left-hand side of this conversion relationship has the unit with the prefix (km), while the right-hand side has the prefix's meaning (1,000) followed by the base unit (m). That's the way you should always write the relationship. The 1 goes with the unit that has the prefix, and the definition of the prefix goes with the base unit. Now we just put the original measurement over 1 to make it a fraction and multiply by another fraction made from the conversion relationship, making sure the m's cancel:

$$\frac{50.0\ \cancel{\text{m}}}{1} \times \frac{1\ \text{km}}{1{,}000\ \cancel{\text{m}}} = 0.0500\ \text{km}$$

There are three significant figures in 50.0 m, and conversion relationships are exact, so they have an infinite number of significant figures. Thus, the answer must have three significant figures, which is why it is 0.0500 km.

I went through all these concepts quickly, because they should all be review for you. If you are confused about any of the things I have discussed, you need to stop reading this book and go to the course website, which is discussed in the introduction. There you will find a link to a PDF of the first chapter of my chemistry course, which goes over these concepts more slowly. You *cannot* continue in this course until you have mastered the material I covered in this section!

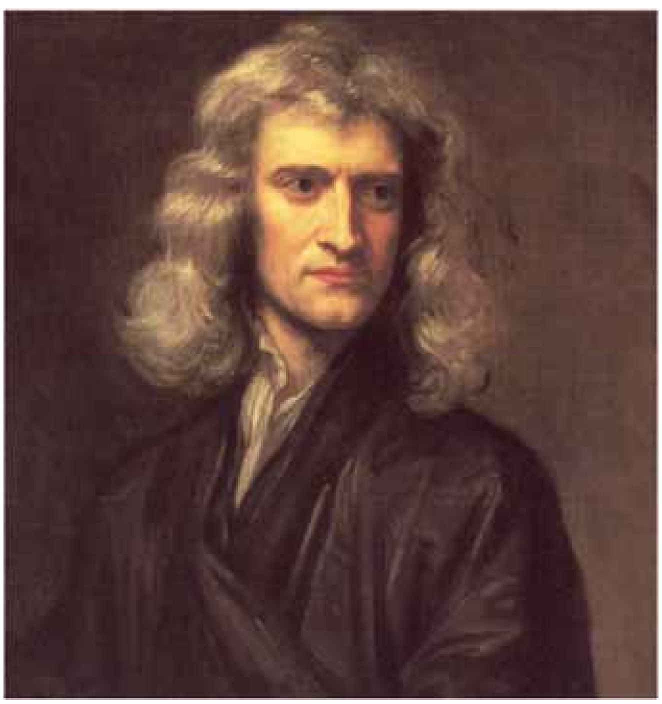
Comprehension Check

1. The density of an object is its mass divided by its volume. What is the density of a rock if it has a mass of 3.40×10^{2} g and a volume of 1.215×10^{-4} m^3?

2. Use the factor-label method to convert 0.0231 g into mg.

Sir Isaac Newton

Much of what you will learn from this course comes from the work of one of the greatest scientists who ever lived: **Sir Isaac Newton**. Born on Christmas day in 1642, he was the son of a farmer. As he grew into adulthood, his mother tried to get him to be a farmer as well. He hated it, however, so he went to Cambridge University and studied mathematics. Since his family wasn't wealthy, Newton paid for his education by working as a servant for the wealthy people at the university. However, he was eventually awarded a scholarship so that he no longer had to do that.



A portrait of Sir Isaac Newton made in 1689

Over the course of his lifetime, he made discoveries in mechanics (the study of motion), optics (the study of light), and astronomy (the study of the planets and stars). In addition, he was one of two people who discovered a new form of math (calculus) that he needed in order to understand his experiments. These discoveries ended up making him quite famous. Queen Anne knighted him in 1705, and when he died, the English poet Alexander Pope wrote the following

> Nature and nature's laws lay hid in night;
> God said "Let Newton be" and all was light.

Like many great scientists of the past and present, Newton was a devout Christian. He spent a lot of time studying the Bible, and he actually wrote more about his Biblical studies than he did about his scientific studies. However, his views were not orthodox. He did not believe in the Trinity, for example. As a result, those works did not receive much attention. Nevertheless, he gave God credit in his scientific works. For example, while giving his scientific analysis of the solar system, he wrote:

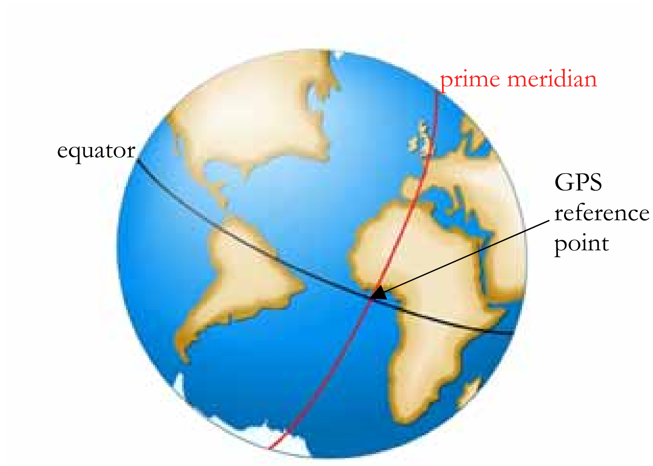
> This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being…This Being governs all things, not as the soul of the world, but as Lord over all…
> (Isaac Newton, *Mathematical Principles of Natural Philosophy*, Encyclopedia Britannica Great Books Series, Vol 34 (1952), pp. 369-370)

Indeed, there are many historians of science and mathematics, like Dr. Morris Kline, who say that Newton's Christian faith was instrumental in guiding his scientific research.

Where Do We Start?

Newton discovered three laws that govern how things move, and I want you to learn them in detail. However, before you can do that, you need to understand some basic terminology related to how we keep track of motion. The first thing you need to understand is how we pinpoint the location of an object. Suppose you want to meet a friend in the park. The park is big, so you arrange a place to meet. You might say, "I will be in front of the building that has the restrooms in it." Once you say that, your friend knows your **position** in the park.

Notice that to give your position, you had to use a **reference point**. In this case, your friend is familiar with the building, so the reference point makes it easy for him to find you. In actuality, all positions depend on a reference point. For example, if you have a navigation app on your phone, it uses global positioning system (GPS) coordinates to determine your position, and those GPS coordinates use the intersection of the equator and the prime meridian as their reference point.



The GPS determines your position relative to the reference point shown in the illustration.

Now suppose you and your friend start walking, and in five minutes, you get a call from another friend. She heard you were at the park and decided to go there as well. Now she wants to meet up with both of you. How would you tell her where to go? If there were no obvious landmarks to guide her, you might say, "We are about one-third of a mile from the building with the restrooms." That would tell your friend the **distance** you are from the building, but that wouldn't be much help to her, would it? After all, to find you, she needs to know the direction in which you walked. To be more helpful, you might say, "We are 0.33 miles east of the building with the restrooms." That's more helpful, since it tells her how far away you are *and* in what direction. This is called your **displacement** from the restroom, and using that, she should be able to find you, as long as you wait for her.

In physics, it is important to distinguish between quantities like displacement and distance. If something I measure includes direction, it is a **vector** (vek' tor) quantity. If it doesn't include information about direction, it is a **scalar** (skay' lur) quantity. Thus, distance is a scalar quantity, while displacement is a vector quantity.

Vector quantity – A quantity that includes direction

Scalar quantity – A quantity that does not include direction

As you progress through this course, you will learn the importance of knowing whether something is a scalar or vector quantity.

It turns out that we can keep track of direction mathematically. That's why the navigation app in your phone is able to guide you to your destination. It knows your displacement from the GPS reference point, and it knows your destination's displacement from the GPS reference point. Since it can keep track of the direction mathematically, it can calculate the direction you need to go in order to reach your destination.

How do we keep track of direction using math? It depends on the situation. The more complicated the situation, the more complicated the math. To keep it simple at first, I will limit the discussion to moving in a straight line. This is called **one-dimensional motion**. If you think about moving in a straight line, you have only two choices for direction. You can move in one direction along the line or in the opposite direction. Because there are only two choices, you can represent direction with a positive or negative sign. You can define one direction as positive, which makes the opposite direction negative.

Think about meeting your friend at the park. Since you walked east from the building, you could call east the positive direction. Thus, you could tell your friend that, defining east as positive, you are 0.33 miles from the building. Because you defined east as positive and then gave a positive distance, you have actually given her a displacement.

Why is this important? Well, suppose you and the friend you are with decide to walk back towards the building to meet up with the friend who just called you. To walk back towards the building, you would be walking west. As a result, you would be walking in the *negative* direction. Suppose you are walking a bit more quickly than her, so you end up traveling 0.20 miles west in order to meet up with her. What is your new displacement from the building? You can probably figure it out in your head, but you need to think through it the way a physicist would. You defined east as positive, so when you got your friend's call, your displacement was 0.33 miles. However, you walked in the opposite direction for 0.20 miles before meeting up with her. Thus, you walked -0.20 miles. Your new displacement from the building is:

$$\text{Total Displacement} = 0.33 \text{ miles} + -0.20 \text{ miles} = 0.13 \text{ miles}$$

Since the total displacement is still positive, you are still east of the building, but you are now 0.13 miles east of it, instead of 0.33 miles east. Make sure you understand this by studying the following example and then doing the problem that appears after it:

Example 1.3

A ball rolls north on the ground for 12.2 meters. Someone then kicks it, and it rolls 13.2 meters south before coming to a halt. What is its displacement from its original starting point?

Once again, you can probably figure this out in your head, but you need to get used to defining direction and using it in mathematical problems. So, let's define north as positive. That means south is negative. Before being kicked, then, the ball rolls 12.2 m. It's positive, because north is positive. After being kicked, it rolls -13.2 m. It's total displacement, then, is:

Total Displacement = 12.2 m + -13.2 m = -1.0 m

Since the total displacement is negative, you know that it is 1.0 m south of its starting point. You don't have to include the actual word "south" in your answer, as long as you say that you defined north as positive. If you do that, then any positive answer would be north, and any negative answer would be south.

Now please understand that it doesn't matter which direction is positive, as long as you make sure that the other direction is negative. For example, you could define south as positive. Of course, that would mean north is negative, so the ball's initial displacement is -12.2 m, and its displacement after the kick is 13.2 m, so when you add them together, you get 1.0 m. But now that south is positive, that still means 1.0 m south.

Before you finish with this example, though, be sure you understand why the correct answer is 1.0 m south, and *not* 1 m south. A mathematician would say that 1.0 m and 1 m are the same, but to a scientist, they are very different. The zero at the end of the number and to the right of the decimal is significant, which means it has been measured. So 1.0 m south is ten times more precise than 1 meter south. How do you know that you must keep that zero? When adding or subtracting, you report your answer to the same precision (decimal place) as the least precise number in the problem. Both of those numbers have their last significant figure in the tenths place. That means they both have a precision of one-tenth of a meter. Thus, your answer must also have a precision of one-tenth of a meter. An answer of 1 m is precise only to one meter. An answer of 1.0 m is precise to one-tenth of a meter.

Comprehension Check

3. A man walks for 570 m west and then turns around and walks 310 m east. What is his displacement from his original starting point?

Speed and Velocity

Let's go back to the park. When the three of you finally meet up, you are 0.13 miles east of the building. Suppose the friend who caught up to you says it took her 2.2 minutes to catch up to you after she reached the building. She likes to do math in her head, so she wants to calculate the speed at which she walked. To do that, she would take the distance she walked and divide it by the time it took her to walk that distance. In physics, we would express it this way:

$$\boxed{\text{speed} = \frac{\Delta d}{\Delta t}} \qquad \text{Equation (1.1)}$$

The "Δ" is the uppercase Greek letter "Delta," and it means "change in." In physics, we often use "d" to stand for distance and "t" to stand for "time." So Equation 1.1 tells you that you can calculate speed by taking the change in distance and dividing by the change in time. From the time she was right in front of the building, to the time she reached you, 2.2 minutes elapsed. Thus, the change in time was 2.2 minutes. This means her speed was:

$$\text{speed} = \frac{\Delta d}{\Delta t} = \frac{0.13 \text{ miles}}{2.2 \text{ minutes}} = 0.059 \frac{\text{miles}}{\text{minute}}$$

Notice how the units in Δd and Δt form the units of the final answer, and notice that both Δd and Δt have two significant figures. Since we are dividing, we count significant figures, so the answer must have two as well. Neither zero in 0.059 mi/min is significant, since neither is between two significant figures or both at the end of the number and to the right of the decimal, so 0.059 also has two significant figures.

Her speed is interesting, because it tells you how fast she was going. However, it doesn't tell you anything about direction. In other words, it is a scalar quantity. If we used displacement instead of distance, we would have direction information, which would give us a vector quantity, which we call **velocity**:

$$\boxed{\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t}} \qquad \text{Equation (1.2)}$$

In this equation, **v** stands for velocity, and Δ**x** stands for change in position, which is the displacement. Notice that the **v** and **x** are boldfaced. That's what I will do in this book to show that they are vector quantities. Scalar quantities will not be boldfaced, so time is a scalar quantity. It contains no direction information. Using Equation 1.2, then, the velocity is:

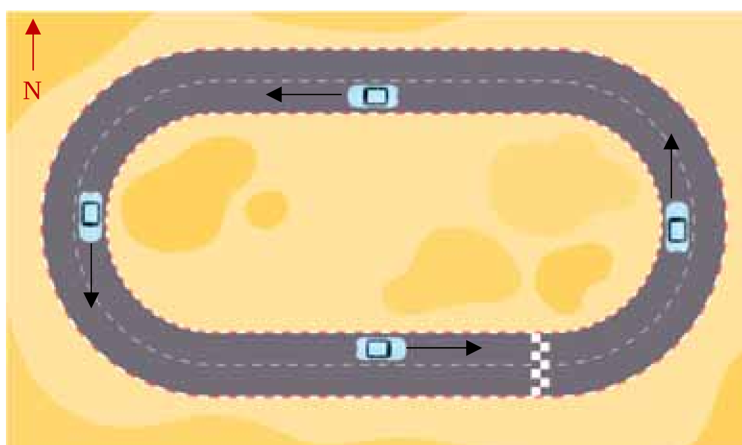
$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta t} = \frac{0.13 \text{ miles east}}{2.2 \text{ minutes}} = 0.059 \frac{\text{miles}}{\text{minute}} \text{ east}$$

Notice that the direction is written after the unit. That's because velocity is the speed plus the direction. I know that in everyday language we use "speed" and "velocity" interchangeably, but they are not interchangeable in physics. Speed is a scalar quantity, while velocity is a vector quantity.

Speed is a scalar quantity, while velocity is a vector quantity.

Now remember, you can also denote direction with positive and negative signs. Thus, if we once again define east as positive, the velocity can just be reported as 0.059 miles/minute, since positive numbers mean the direction is east. Alternatively, had you defined west as positive, the velocity would be -0.059 miles/minute.

While you might not think the distinction between velocity and speed is important, it is *very* important in physics. In fact, there are situations in which an object's speed is constant, but its velocity changes. Consider, for example a car traveling on an oval racetrack. Suppose it travels around the track at a constant speed of 90 kilometers per hour (km/hr). Obviously, its speed doesn't change, but what about its velocity? Look at the illustration on the right, where the red letter and arrow tell you which way is north. At the top of the oval, the car is traveling with a velocity of 90 km/hr west. However, on the left side of the oval, it is traveling with a velocity of 90 km/hr south. At the bottom of the oval, its velocity is 90 km/hr east, and on the right, the velocity is 90 km/hr north. Thus, while its speed stays the same the entire time, its velocity changes! In physics, changes in velocity are actually more important than changes in speed, so you need to get used to thinking about direction when you are analyzing an object's velocity.



While the speed of this car is the same at all the positions shown in the illustration, its velocity is different at each position.

Make sure you understand how to calculate speed and velocity by studying the following example and solving the problem that appears after it.

Example 1.4

Remember that at the park, you traveled 0.33 miles east, then turned around, and traveled 0.20 miles west to meet your friend. Suppose the total time you spent doing this was 8 minutes. What was your speed? What about your velocity?

Remember that speed is the change in *distance* over the change in time. The total distance you traveled was:

$$\text{Total Distance} = 0.33\ \text{miles} + 0.20\ \text{miles} = 0.53\ \text{miles}$$

$$\text{speed} = \frac{\Delta \text{d}}{\Delta \text{t}} = \frac{0.53\ \text{miles}}{8\ \text{minutes}} = 0.07\ \frac{\text{miles}}{\text{minute}}$$

Notice that since 8 minutes has only one significant figure, the answer can have only one significant figure, so your speed is 0.07 miles/minute.

On the other hand, velocity is the change in *displacement* over the change in time. Remember from before that once we defined east as positive your total *displacement* was 0.13 miles, which means 0.13 miles east. That means your velocity was:

$$\mathbf{v} = \frac{\Delta \mathbf{x}}{\Delta \text{t}} = \frac{0.13\ \text{miles}}{8\ \text{minutes}} = 0.02\ \frac{\text{miles}}{\text{minute}}$$

That means your velocity was 0.02 miles/minute. Once again, you can add the word "east" if you like, but since we defined east as positive, we know that any positive velocity is east.

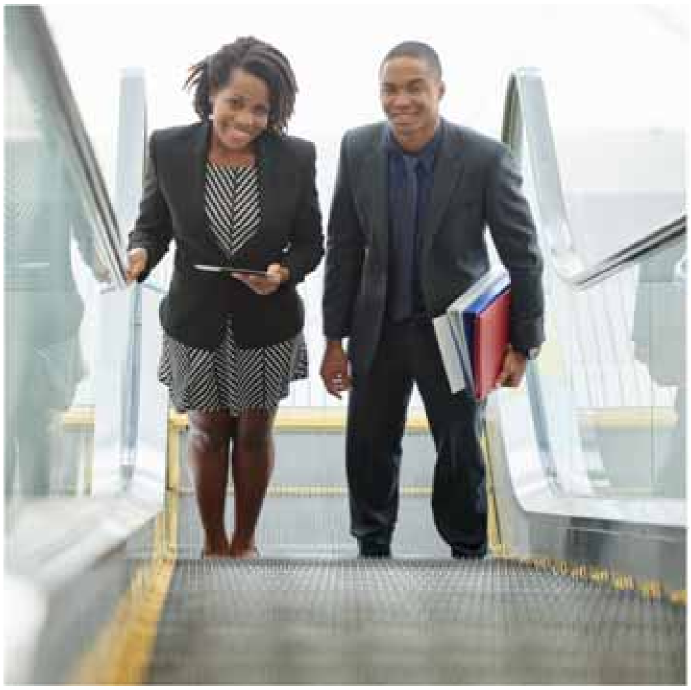
Comprehension Check

4. A bicyclist rides 4.61 km east. He then stops and rides 4.92 km west. If the trip takes him 0.732 hours, what is his speed? What is his velocity?

Velocity is Relative

When you are riding in a car and looking out the window, you see trees, houses, stoplights, etc. While they seem to be moving past you in a direction opposite of the way you are moving, you "know" that you are the one moving and the things you see out the window are not. How do you know that? Because you know what a car does, and you know that trees, houses, and stoplights don't move. Your conclusion that you are moving but the things you are looking at are not moving is a result of your experience, not a direct result of your senses. To your senses, you are not moving. Instead, the trees, houses, and stoplights are moving.

Now consider a slightly different situation. Suppose you are on an escalator with a friend, and then you see another friend who is on the floor at the top of the escalator. He is standing there waving at you. Which friend is moving? If you look at your friend on the escalator, she doesn't seem to be moving. She



Relative to each other, these two people are not moving, but they are moving relative to anyone standing on the floor at the top or bottom of the escalator.

stays next to you the entire time. You "know" the friend who is waving at you is not moving, because he is just standing there. However, you and your other friend are getting closer and closer to him. Once again, which friend is moving?

The answer is that you and both friends are moving. It just depends on what your reference point is. If you are the reference point, your friend on the escalator is not moving, but your friend at the top of the escalator is moving towards you. However, if your friend at the top of the escalator is the reference point, you and your friend on the escalator are moving towards him, but he is not moving. This is because velocity is relative. You cannot determine a velocity until you define a reference point relative to which you can define the motion. To better understand this, I would like you to perform the following experiment.

Experiment 1.1: Velocity is Relative

Materials

- A paper or Styrofoam cup
- A stepladder or a place someone can safely stand that is high above the floor or the ground
- A pen
- Water
- A large basin to catch water (if you can't do the experiment outside)
- Someone to help you

Instructions

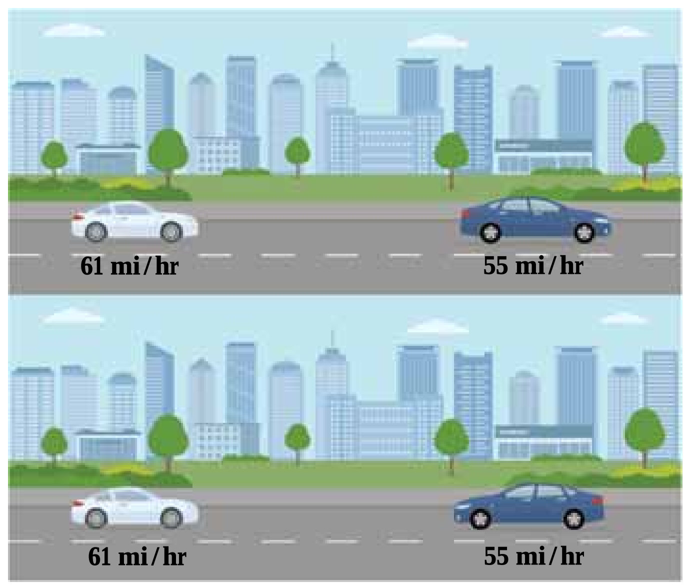
1. Use the pen to poke a hole in the bottom of the cup. The hole should be as big around as the pen.
2. If the weather is okay, take the stepladder outside and set it up securely on a flat piece of ground. Alternatively, find a high place outside from which it is safe to drop things.
3. If the weather is not okay, set the stepladder on a floor that will be okay if it gets wet. Alternatively, find a high place from which it is safe to drop things on a floor that can get wet. Put the basin on the floor so that anything you drop will land in it.
4. Have your helper fill the cup with water, plugging the hole with a finger so that no water will fall out.
5. With his or her finger continuing to plug the hole, have your helper go to the highest step on the stepladder that is safe (or the high place you have chosen).
6. Have your helper hold the cup so it is in front of him or her and the hole that is being plugged points down towards the ground.
7. If you are doing this indoors, have your helper hold the cup over the basin so that when water leaks out of the hole, it will fall into the basin.
8. Stand in front of your helper on the floor (or ground) so you are facing the cup and can easily see the finger your helper is using to plug the hole in the bottom of the cup.

9. Have your helper unplug the hole and watch the water start leaking out of the hole and falling down to the ground (or into the basin).
10. After you have watched the water leak out of the hole for just a moment, have your helper plug the hole again long before all the water runs out.
11. Now have your helper release the cup as he unplugs the hole. As the cup falls, keep your eyes on the bottom of the cup where water was leaking out. What changes once the cup is in motion?
12. If you didn't notice a change, repeat the experiment. You can also record it with a phone camera and watch the video.
13. Clean up any mess that might have been made, and put everything away.

What did you see in the experiment? If it went well, you should have initially seen a stream of water falling out of the cup. However, when your helper unplugged the hole and dropped the cup at the same time, the water should have stopped falling out of the cup. Why? Let's take the cup as a reference point. When your helper unplugged the hole, water started moving relative to the cup, and it streamed out of the hole. However, when your helper dropped the cup, it fell with the water. As a result, relative to the cup, the water was no longer moving. Thus, it could not fall out of the hole.

Another way to think about this is to use you as the reference point. When your helper unplugged the hole, the cup had a velocity of zero relative to you. However, the water had a velocity directed towards you. If we define towards you as the positive direction, then, the water had a positive velocity. However, when your helper dropped the cup, both the cup *and* the water had the same positive velocity. The **relative velocity** is the difference between those two velocities, which would be zero. Thus, the relative velocity of the cup and the water was zero, so the water did not move relative to the cup.

The fact that velocity is relative can be very important. Consider, for example, the two situations pictured in the illustration on the right. In each situation, the two cars are approaching each other, but in which case are they approaching each other more quickly? Obviously, it's in the situation pictured at the bottom of the illustration. Using the concept of relative velocity, however, we can say exactly how quickly they are approaching one another in each situation.



In both situations, the cars are approaching each other. However, they are approaching each other more quickly in the situation shown at the bottom.

Let's start with the situation shown at the top of the illustration. What does the driver in the white car see? He sees himself getting closer to the blue car. How quickly is that happening? To answer that, we determine the relative velocity. We can do that by subtracting the reference object from the moving object.

$$\boxed{\text{relative velocity} = \text{velocity of moving object} - \text{velocity of reference object}} \quad \text{Equation (1.3)}$$

Yes, I know, both cars are really moving. However, if we want to know what the driver in the white car sees, he is our reference, so we treat him as stationary and the other car as moving. Now remember, velocity includes direction, which we denote with positive and negative signs. Let's define motion to the right as positive. In this case, then, both cars have a positive velocity, since they are both moving to the right. Since the white car's velocity is 61 mi/hr, while the blue car's velocity is 55 mi/hr. The relative velocity, then, is:

$$\text{Relative velocity} = 55\ \frac{\text{mi}}{\text{hr}} - 61\ \frac{\text{mi}}{\text{hr}} = -6\ \frac{\text{mi}}{\text{hr}}$$

What does that mean? Remember, we are using the white car as our reference. So that means the white car sees the blue car traveling to the left (towards him) at 6 miles per hour. This would be the same as the white car sitting still, and the blue car traveling towards it at 6 miles per hour. Note that since we are subtracting, we look at precision to determine how to report our answer. Both numbers have their last significant figure in the ones place, so the answer must be reported to the ones place. That's why it is -6 mi/hr and not -6.0 miles/hr.

Now remember, since velocity is relative, we can look at this from the blue car driver's perspective as well. The velocities haven't changed, so using the blue car as a reference and continuing to define motion to the right as positive, the relative velocity is:

$$\text{Relative velocity} = 61\ \frac{\text{mi}}{\text{hr}} - 55\ \frac{\text{mi}}{\text{hr}} = 6\ \frac{\text{mi}}{\text{hr}}$$

So the driver of the blue car sees the white car moving to the right (towards her) at 6 miles per hour. This is the same as a situation in which the blue car is sitting still, and the white car is moving towards it at 6 miles per hour. In fact, from a physics point of view, the situation pictured in the top part of the illustration is the same as a situation in which the white car is sitting still, and the blue car is moving left (towards it) at 6 miles per hour. It is also the same as a situation in which the blue car is sitting still and the white car is moving right (towards it) at 6 miles per hour.

Now let's think about the bottom situation. In that case, the white car still has a velocity of 61 mi/hr. However, the blue car is moving to the left, so its velocity is -55 mi/hr. Using the white car as a reference, then:

$$\text{Relative velocity} = -55\ \frac{\text{mi}}{\text{hr}} - 61\ \frac{\text{mi}}{\text{hr}} = -116\ \frac{\text{mi}}{\text{hr}}$$

This means relative to the white car, the blue car is moving to the left (towards it) at 116 mi/hr. Similarly, from the blue car's perspective:

$$\text{Relative velocity} = 61\ \frac{\text{mi}}{\text{hr}} - -55\ \frac{\text{mi}}{\text{hr}} = 116\ \frac{\text{mi}}{\text{hr}}$$

So relative to the blue car, the white car is traveling to the right (towards it) at 116 miles per hour. Make sure you can analyze this kind of situation by solving the problem below.

Comprehension Check

5. In a long-distance race, the runner in the lead has a velocity of 2.9 m/s west. The runner in second place has a velocity of 2.8 m/s west. What is the velocity of the runner in second place relative to the runner in the lead?

Relating Velocity and Displacement

Since Equation (1.2) uses the displacement and the change in time to determine v, we can use it (and our algebra skills) to determine any one of those quantities if we are given the other two. This can be an important part of analyzing physical situations, so I want to make sure you understand how to do it by studying the following example problem.

Example 1.5

A car is traveling with a velocity of 16.4 m/s south. If it must end up 3.4 km south of its present location, how long will it have to travel?

Now remember, I don't always have to tell you the physical quantity that is being measured. The units (and the presence or absence of a direction) will tell you. I told you that 16.4 m/s south was the velocity, but I didn't need to identify it. The unit (m/s) tells you that a speed or velocity was measured, and the direction tells you it's velocity. I didn't tell you what 3.4 km south is, but the unit does. The unit tells you it is either distance or displacement, because that's what meters (or any prefix with meters) measure. Since there is also a direction, you know I gave you the displacement.

Units are important for another reason as well. If you look at the problem, the distance unit used in the value of velocity is m, which stands for meters. The unit for the displacement is km, which stands for kilometers. *Those two units are inconsistent*. They both measure displacement, but they aren't the same measure. When we do math, we need to make sure that all the units are consistent with one another. Thus, every displacement unit must be either meters or kilometers. As a result, I will need to change one of the units to make it consistent with the other one. I will change km into m, since that's a bit easier than turning m/s into km/s.

$$\frac{3.4\ \cancel{\text{km}}}{1} \times \frac{1{,}000\ \text{m}}{1\ \cancel{\text{km}}} = 3{,}400\ \text{m}$$

This is one of the many reasons you need to understand how to convert units. You will be doing it *a lot* when you solve problems.

Now that we have the units consistent, we can continue. Defining south as positive makes both the velocity and displacement positive, which means Equation (1.2) becomes

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

$$16.4\ \frac{\text{m}}{\text{s}} = \frac{3{,}400\ \text{m}}{\Delta \text{t}}$$

We can now use algebra to solve for Δt:

$$\Delta \text{t} = \frac{3{,}400\ \cancel{\text{m}}}{16.4\ \frac{\cancel{\text{m}}}{\text{s}}} = 210\ \frac{1}{\frac{1}{\text{s}}} = \underline{210\ s}$$

Notice that since we are dividing, we must count significant figures. 3,400 m has two, while 16.4 m/s has three, so the answer can only be reported to two significant figures, which is why I rounded the answer (207.317…) to 210. Also, look at the units. The meters cancel, which is why they had to be made consistent with one another. That leaves a complicated fraction. If you don't understand why that fraction works out to seconds, think about how we divide by a fraction. We invert and multiply. Thus, $1 \div \frac{1}{\text{s}}$ is the same as $1 \times \frac{\text{s}}{1}$, which works out to s.

That was a pretty simple problem, but I wanted to show you how to solve it so you could get used to one of the common things we must do when analyzing physical situations – making sure the units agree. This is very important

Before solving a problem, look at the units and make sure they are consistent. If they are not, convert the inconsistent units before you continue.

Now let's look at what appears to be a more difficult problem.

Example 1.6

Two toy cars move on a track. The lead one travels at 1.5 m/s west, while the one behind is traveling at 1.6 m/s west. If they collide after 1.1 minutes, how far apart were they initially?

I didn't have to tell you that I was giving velocities, since the units and directions tell you what they are. Based on the velocities, you can tell that the car behind will slowly catch up to the car in front. You might think this is a hard problem to solve, since both cars are moving. However, remember that since velocity is relative, you can treat this problem as if one car is sitting still, and the other one is moving at the cars' relative velocity. That makes everything easy! So let's treat the car in front as if is sitting still. If that's the case, the car behind will be moving at the relative velocity. We have to define a direction, so let's say that motion to the west is positive, since both cars are moving that way.

$$\text{Relative velocity} = \text{Velocity of moving object} - \text{Velocity of reference object}$$

$$\text{Relative velocity} = 1.6\ \frac{\text{m}}{\text{s}} - 1.5\ \frac{\text{m}}{\text{s}} = 0.1\ \frac{\text{m}}{\text{s}}$$

Since we are subtracting, we look at the decimal place of the numbers. Both of them have their last significant figure in the tenths place, so the answer must have its last significant figure in the tenths place as well.

So this situation is equivalent to the front car sitting still, and the other car approaching it at a velocity of 0.1 m/s west. Since we know the time, we can use Equation (1.2) to determine the displacement that the car experiences. However, we need the units to be consistent, and they are not. The time unit in the velocity is seconds, while the time it takes for them to collide is in minutes. Thus, we need to convert. I will convert minutes to seconds:

$$\frac{1.1\ \cancel{\text{min}}}{1} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} = 66\ \text{s}$$

Remember, the conversion relationship is exact, so it has infinite significant figures. Thus, 1.1 limits the answer to two significant figures. Now we can use Equation (1.2):

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

$$0.1\ \frac{\text{m}}{\text{s}} = \frac{\Delta\mathbf{x}}{66\ \text{s}}$$

We can now use algebra to solve for $\Delta\mathbf{x}$:

$$\Delta\mathbf{x} = 0.1\frac{\text{m}}{\cancel{\text{s}}} \times 66\ \cancel{\text{s}} = \underline{7\ \text{m}}$$

Since we are multiplying here, we must count significant figures. 0.1 m has one, while 66 s has two, so the answer can have only one. Notice also that the unit of seconds cancels, which is why we get a proper unit for the displacement. Finally, we could have used the rear car as the reference, and we would have gotten the same answer.

Make sure you understand what you just read by solving the two problems below.

Comprehension Check

6. A runner is moving east at 3.45 m/s. After 4.0 minutes, what will be his displacement?

7. Two trains are on the same track. One is traveling at 23 m/s east and the other at 19 m/s west. If the first train is 16.5 km west of the second, how long before they collide?

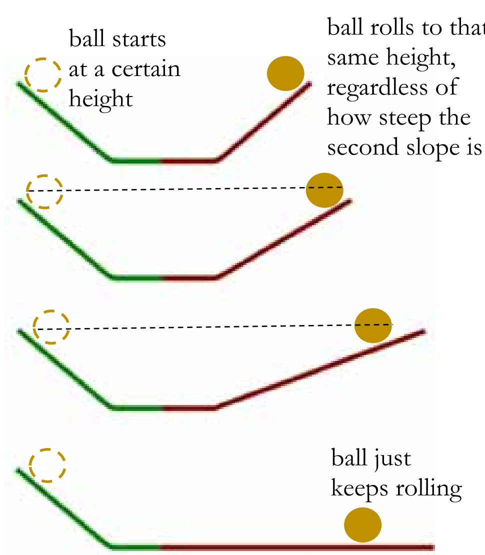
Newton's First Law of Motion

Suppose you are walking down the sidewalk and you see a rock, so you kick it. It will bounce down the sidewalk for a while, but it will eventually come to rest, right? The same thing happens when you throw a ball. It will move in the direction you threw it for a while, but it will eventually come to rest. In general, we can make things move, but eventually, they stop moving. This led Aristotle, an important philosopher who lived in the 4th century BC, to conclude that objects here on earth "prefer" to be at rest. You can force them out of their preferred state for a while, but they will eventually end up back in their preferred state – at rest.

This portrait of Galileo Galilei is thought to be among the last painted before his death in 1642.

Aristotle was such an important philosopher that this view was the dominant view among scientists (they were called "natural philosophers" back then) for about 2,000 years! While a few natural philosophers argued against it over the years, the one who definitively showed it to be wrong was Galileo Galilei (1564-1642), a devout Christian who studied both Scripture and science so that he could learn as much about God as possible. Indeed, in a letter he wrote to the Grand Duchess of Tuscany in 1615, he stated, "…for the holy Bible and the phenomena of nature proceed alike from the divine Word, the former as the dictate of the Holy Ghost and the latter as the observant executrix of God's commands."

The experiments and reasoning he used to contradict Aristotle are worth learning, because they show you how a good physicist interprets experiments. He started by rolling a smooth ball down a smooth ramp and then up another smooth ramp. He noted that if the ramps and ball were smooth enough, the ball would roll down the first ramp and then roll up the second ramp until it reached the height from which it was first released. Interestingly enough, this was independent of the slope of the second ramp. No matter how far the ball had to travel along the second ramp, it would continue to travel until it reached the original height from which it was released, as shown in the illustration on the right. This led Galileo to reason that if there were no ramp for the ball to roll up, the ball would continue to roll forever. In practice, of course, that wouldn't happen, because **friction** would eventually stop the ball. However, Galileo made the ball and ramps very smooth to reduce the effect of friction. That way, he could reason through what would happen if friction didn't exist.



An illustration of Galileo's experiment that contradicted Aristotle

Based on his experiments, then, Galileo decided that the only reason objects seem to have a preferred state is because there is a force called friction between the object and what it is moving on or moving through. Friction slows the object down until it stops. However, if friction weren't there, an object that was in motion would just continue in motion forever.

Newton used Galileo's experiments and a few of his own to state what we now call **Newton's First Law** of motion.

An object at rest or moving with a constant velocity will continue in that state until acted on by a net force.

In other words, if nothing pushes or pulls on an object, its velocity will not change. If you are confused about the word "net," don't worry about it. As you will learn later, forces can add to one another, which means that two equal but opposite forces can cancel each other out. If there are a lot of forces acting on an object, but they all cancel each other out, there is no net force, so the object behaves as if there is no force acting on it at all. You will learn more about that in the next chapter.

Experiment 1.2: Newton's First Law

Materials
- A rectangular baking pan or a tray with a lip running around the edge
- A large, heavy book or stack of books
- A marble or small ball, like a golf ball
- A smooth, flat counter

Instructions
1. Rest the baking pan on the counter so that it has plenty of room to slide to the right.
2. Put the books or stack of books about a meter (three feet) to the right of the tray. If the counter isn't quite that long, just leave as much space as possible between the book and the tray.
3. Put the ball in the pan so it rests against the left wall of the pan or the left lip of the tray, as shown in the illustration below.

4. Put your left hand on the left side of the pan and use it to push the baking pan along the counter to the right (towards the book) at a steady speed. Don't move it too quickly, because you want the book to stop its motion.
5. Observe what happens to the ball when the baking pan's motion is stopped by the book.
6. Reset the tray to where it was originally.
7. Remove the book from the counter.
8. Put the ball in the tray so that it rests against the *right* wall of the baking pan or right lip of the tray, as shown in the illustrations below.

9. Once again, put your left hand on the left wall (or lip) and push the pan or tray to the right as quickly as you can without losing control. What does the ball do this time?
10. Put everything away, but make sure you know where the ball is, because you will use it in another short experiment later on.

What happened in the experiment? As you slid the tray across the counter in the first part of the experiment, the ball moved with the baking pan, but when the pan was stopped by the book, the ball kept rolling, didn't it? That's because the ball and pan were originally at rest, but you applied a force to the tray, which caused the tray to start moving to the right. The wall of the pan (or the lip of the tray) applied a force to the ball, causing it to move with the pan (or tray). The book applied a force to the pan, which stopped the pan. However, there was nothing to apply a force to the ball. Thus, as Newton's First Law requires, the ball continued on with the same velocity. As a result, it started rolling until the other side of the pan could apply a force to change its motion.

In the second part of the experiment, the ball rolled to the left in the pan as soon as you started moving the pan to the right. That's because the tray and the ball were at rest. You applied a force to the pan to make it move, but the ball had nothing to apply a force on it. Thus, it stayed at rest. Since the pan was moving right and the ball was at rest, the ball seemed to be rolling to the left inside the pan. However, it was at rest relative to the counter. Once again, this is exactly what Newton's First Law requires.

In actuality, of course, there was a force acting on the ball. It is the friction that Galileo recognized, and it exists whenever an object tries to move in or on something.

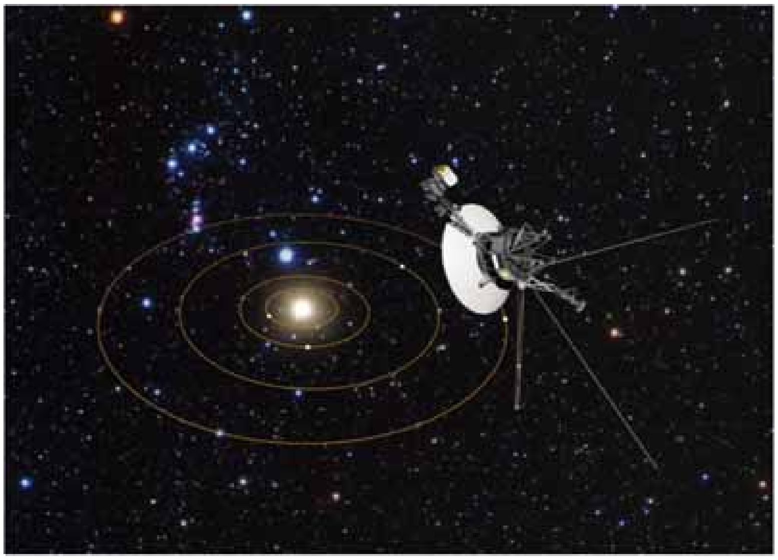
<u>Friction</u> – A force that resists motion when two bodies are in contact

In this case, the ball and pan were in contact. That means there was friction, which resisted any relative motion between them. However, that force was small. As a result, when the ball had a velocity to the right in the first part of the experiment, friction wasn't able to effectively resist any relative motion. Thus, when the pan stopped, the ball continued to move to the right, at very close to the same velocity it originally had. In the same way, in the second part of the experiment, the ball was being pushed to the right a bit by friction so as to stop any relative velocity between the ball and the pan. However, it wasn't strong enough, so the ball acted as if its velocity remained pretty much zero when the pan started to move.

Of course, Newton's First Law has many implications. For example, it's the reason you need to wear a seat belt when you are in a moving vehicle. If the vehicle comes to a stop, you will continue moving with the forward velocity you had while the car was in motion. If the stop is slow, the friction between you and your seat will be strong enough to slow you down with the car. However, if the stop is sudden, friction will not be strong enough to slow you down much, and like the ball in the first part of your experiment, you will continue to move forward. This can cause you to be thrown against the dashboard, or worse yet, the windshield. However, a seat belt will be able to exert a strong enough force to stop your forward motion, saving you from serious injury.

Now remember, most objects eventually come to rest regardless of their velocity, because friction is a force that slows them down, eventually stopping them. However, if you get rid of friction, that doesn't happen. While it's hard to get rid of friction here on earth (even air produces friction against anything moving through it), there is very little friction in space. As a result, objects that have been given a velocity in space continue to move with that velocity for a long, long time.

Consider, for example, the robotic Voyager spacecrafts. Voyager 2 was launched from earth on August 20, 1977. Slightly more than two weeks later, Voyager 1 was launched. They used most of their fuel just to leave the earth and be put on course, but since then, they have used very little fuel. After all, since there is very little friction in space, there is hardly any force acting on them. As a result, they have been traveling with the same velocity since they stopped using their fuel for propulsion in 1989. Now, more than 30 years later, they are still traveling with pretty much the same velocity because of Newton's First law. In fact, they have been traveling for so long that they have actually left our solar system and are now traveling through interstellar space! They are the only human-made objects that have left the solar system. They don't need anything pushing them as they travel. They continue to move because of Newton's First Law.



An artist's conception of one of the Voyager spacecrafts observing the solar system from outside. The yellow circles represent the orbits of Jupiter, Saturn, Uranus, and Neptune around the sun.

Now, of course, in order for them to continue to gather data and communicate it back to us, they must have electrical power for their instruments and communication equipment. They get that from a generator which turns the heat produced by the decay of a radioactive substance into electricity. However, the radioactive substance will eventually run out of sufficient energy to power the electrical systems, and while the spacecrafts will still be traveling through space, we will lose contact with them. Current indications are that the scientific instruments will not have enough power to operate starting in about 2025, but the communication systems might be able to last about 10 years beyond that.

Comprehension Check

8. Suppose you are sitting in a plane that is coasting along. Suddenly, the plane drops a few hundred feet without warning. If you aren't wearing your seat belt, in what direction relative to the seat will you travel?

9. Two identical blocks traveling on two different flat surfaces are given the same velocity. Block A comes to rest in 2.1 meters, while block B comes to rest in 1.7 m. Which experienced a weaker frictional force?

This Can Be a Bit Tricky!

While Newton's First Law makes sense when it is explained, sometimes it is hard to understand how it applies in certain situations. Consider, for example, a satellite that is orbiting the earth. Most satellites move relative to the earth's surface so that they can view different parts of the earth at different times. However, there are **geosynchronous** (jee oh' sin kruh' nus) satellites that stay above the same part of the earth all the time. In other words, relative to some fixed point on the planet, they never move. Many communication satellites are like this so that you always know how to orient your antenna so that it points directly to the satellite.

Even though a geosynchronous satellite never moves relative to a fixed point on the earth's surface, it still moves relative to the center of the earth. That's because the earth rotates, so to stay above the same spot, the satellite must move with that rotation. Thus, because every fixed point on the earth must make one full circle every 24 hours, a geosynchronous satellite must make one full orbit every 24 hours. That means it is moving in its orbit at a constant speed.

Now let me ask you a question. Is the satellite experiencing a net force? You might be tempted to say "no." After all, Newton's First Law says that a net force will change an object's velocity. Since the satellite's speed is not changing, you might be tempted to say there is no force. However, you would be wrong, because speed is not velocity. Velocity includes direction. Even though the satellite is traveling at a constant speed, it is continually changing direction in order to keep traveling in a circle. As a result, its velocity is continually changing. To understand what I mean, perform the following experiment.

Experiment 1.3: Motion in a Circle

Materials

- A marble or small ball, like a golf ball
- A smooth floor (A carpeted floor will work, as long as the carpet is reasonably smooth)
- A circular container that is either glass or plastic (You need to be able to see the ball through the bottom of the container. You don't need to see it really clearly – you just need to see it.)

Instructions

1. Put the ball on the floor.
2. Turn the container upside down and place it over the ball so that the ball rests against the side.
3. Move the container so that the ball inside starts traveling in a circle against the side of the container. Get it going as fast as you can.
4. Stop moving the bowl and watch the ball. It should continue to travel in a circle until friction brings it to a halt.
5. Repeat step 3 to get the ball moving in the circle again.
6. Stop moving the bowl, but as you watch the ball, lift the bowl straight up in the air while you continue to watch the ball. How does the ball travel after you lift the bowl?
7. Repeat steps 5 and 6 a couple more times. Each time, note how the ball moves once the bowl is lifted.
8. Put everything away.

What did you see in the experiment? As long as the container was there, the ball would travel in a circle. However, as soon as you lifted the container, what happened? The ball started traveling in a straight line. Why? Because of Newton's First Law. The only reason the ball traveled in a circle to begin with was because the container was exerting a force on the ball. That might have been obvious when you used the container to get the ball moving. However, once you stopped moving the container, it was still exerting a force on the ball. That force kept changing the ball's direction, which means it was changing the ball's velocity. When you lifted the container up, the ball no longer had a net force acting on it, so it traveled with a constant velocity, which means it started moving in one direction.

This is true for anything that travels in a circle. So the geosynchronous satellite I mentioned previously is also being acted on by a force that keeps changing its direction so that it doesn't move in a straight line; it moves in a circle. What is that force? It's the force of gravity. Without the gravitational attraction between the satellite and the earth, the satellite would move in a straight line, because there would be no force to change its velocity. We will examine this in much more detail when we discuss gravity and how it works. For right now, you just have to realize that gravity is the force that keeps the satellite from traveling off into space like the Voyager spacecrafts continue to do.

Let's think through one more tricky situation. Suppose you are piloting a bomber, and your mission is to drop bombs on an enemy city. Your bomber is flying due west at 900 kilometers per hour. You see from your navigation equipment that you are approaching the city. The bombs you are going to drop have no propulsion system of their own; they just drop like rocks (okay, like *explosive* rocks) when you release them. When should you let the bombs drop?

Well, you know that gravity pulls things down, so when you release the bombs, you expect them to fall down. That expectation is valid. However, they start moving down because a force (the force of gravity) changes their downward velocity from 0 to something nonzero. However, the bombs are traveling with you in your bomber. As a result, they have a westward velocity as well. They will continue with that westward velocity unless some force changes it. You might think the force of gravity will change the westward velocity, but it can't; it only pulls down. Thus, it changes the downward velocity from zero to something large. However, it doesn't change the westward velocity, because it doesn't push or pull in that direction. As a result, the bombs will continue to travel with their westward velocity.

So when should you release the bombs? If you wait until you are above the city to release them, they will continue to travel west as they fall, hitting the ground west of the city. You should release them when you are east of the city. That way, as they fall, they will continue to travel westward with the bomber as they also start traveling downward due to the force of gravity. If you time it right, they will hit the ground at the moment they have traveled far enough west to hit the city.

Each bomb that is dropped continues to travel with its bomber because of Newton's First Law. Thus, they keep up with the bomber's velocity as they fall.

To make sure you understand this, look at the picture on the left. It was taken while the U.S. 8th Air Force bombed Dresden, Germany's railway center on April 17, 1945. Look at the trail of bombs beneath each plane. The bottom bomb in each line was dropped before the top bomb, yet all the bombs from each bomber are still directly below the bomber. That's because as the bombs dropped, they were still traveling with the speed they had while they were in the bomber. Since the bomber continued with that speed, all the bombs kept up with the bomber, no matter how long they had been falling!

Now once again, there is still friction in this situation. Air resists motion through it, so the bombs are slowed down a bit by friction. However, they are designed to reduce that friction, and while it does slow them down a bit, they aren't in the air for very long, so the effect is small. Nevertheless, it can be accounted for if you are looking for a precision strike.

Before I leave this discussion, I do want to introduce one bit of terminology. Newton's First Law tells us that objects stay at their present velocity unless acted on by an outside force. In other words, they resist changes to their velocity. That is often called **inertia** (ih nur' shuh).

<u>Inertia</u> – The tendency of a body to resist changes in its velocity

How do objects "resist" these changes? I will discuss that in the next chapter. For right now, just understand that inertia is often used as a way to refer to Newton's First Law. For example, you could say that the bombs in the photo above are all lined up under their bombers because of each bomb's inertia. Each bomb resists changes to the velocity it had while in the bomber, so it kept up with the bomber as it fell. Because of this, Newton's First Law is often called the **Law of Inertia**.

Comprehension Check

10. Suppose you shoot an arrow straight up while riding in the back of a pickup truck that is traveling down the road at a constant velocity. Ignoring friction, where will the arrow land when it comes back down?

Change Is a Part of Life

Newton's First Law tells us that an object's velocity doesn't change unless there is a net force acting on it. Of course, that happens all the time, because there are a lot of things that can exert forces on objects. When you kick a rock, you are exerting a force on it, so the rock's velocity changes. When you catch a ball, you are exerting a force to stop it, so once again, its velocity changes. Thus, we need to start thinking about the details of how velocity changes. To start the process, perform the following experiment.

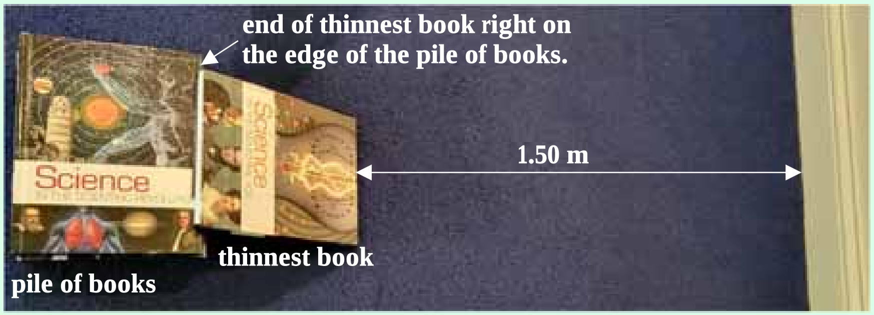
Experiment 1.4: Changing Velocity

Materials

- Several hardcover books with different thicknesses (One of them should be the thinnest hardcover book you have.)
- A marble or other small ball, like a golf ball
- A meterstick or measuring tape
- A smooth floor (It can be carpeted.)
- A stopwatch or any other timing device that can read to at least the tenth of a second

Instructions

1. Find a portion of the floor that is clear for about two meters and ends at a wall.
2. Lay the thinnest hardcover book down so its nearest end is 1.50 m from the wall.
3. Holding that end down so it stays 1.50 m from the wall, put several books underneath the far end to make a ramp. The inclined book should not stick up much above the other books. Its far end should be sitting right on the edge of the pile of books (see the photo on the right).



4. Hold the ball at the very top of the ramp you just made and release it. Does it roll the 1.50 m and then hit the wall? If not, add more books so that the ramp is steeper, but remember to hold the near end so that it stays 1.50 m from the wall. Once the ball rolls the 1.50 m and hits the wall, go to the next step.
5. Hold the ball at the very top of the ramp and release it. When you see it hit the floor, start your timer. When you hear it hit the wall, stop the timer. Record the time you measured.
6. Repeat step 5 four more times.
7. Now move the entire ramp so that the near end is 1.00 m from the wall. Make sure that once again, the thinnest hardcover book does not stick up much above the other books. Its far end should once again be sitting right on the edge of the pile of books so it is at the same height as it was before.
8. Repeat step 5 a total of five times.
9. Compute the average of the first five times that you measured.
10. Divide the distance the ball traveled during that time (1.50 m) by the average time. That is the velocity of the ball over those 1.50 m.
11. Compute the average of the second five times that you measured.
12. Divide the distance the ball traveled during that time (1.00 m) by the average time. That is the velocity of the ball over those 1.00 m.
13. Compare the two velocities.
14. Clean up your mess and put everything away.

You might be wondering why I had you repeat your measurements five times and average them. I will discuss that in the final section of this chapter. For right now, I want you to concentrate on what happened in the experiment. When you held the ball at the top of the ramp, it had a velocity of zero. However, when you released it, it began rolling down the ramp. Thus, its velocity began to change, which tells you that a force must have been acting on it. The force was gravity, which was pulling the ball down the ramp. Once the ball reached the floor, that force could no longer change the ball's velocity. However, the ball already had a lot of velocity from rolling down the ramp, so Newton's First Law says that it will continue rolling with that velocity unless another force acts on it.

Was there another force acting on it? You can answer that question by comparing the two velocities you calculated. You kept the ramp the same in both cases, so the velocity the ball had when it hit the floor should have been the same in both cases. If no force was acting on the ball, then the velocities you calculated should have been the same as well. However, they probably weren't. Most likely, the first velocity (the one calculated with 1.50 m) was lower than the second velocity (calculated with 1.00 m). Thus, there was a force acting on the ball. That force, of course, was friction. Friction fought against the motion of the ball, slowing it down as it went. The longer the ball rolled, the more friction could fight its motion, so the slower the ball rolled.

Did you notice that the ball was slowing down as it rolled on the floor? You might have. In the end, it had its highest velocity when it hit the floor, and it had its lowest velocity when it hit the wall. At any point in between, its velocity was getting progressively lower. This brings up an important point about Equations (1.1) and (1.2). They allow you to calculate the *average* speed and *average* velocity over the time interval you use. Since the ball was slowing down the entire time in the experiment, the two velocities you calculated were somewhere in between the velocity the ball had when it hit the floor and the velocity the ball had right before it hit the wall.

In order to be accurate in our description of motion, then, we have to distinguish between the ball's **average velocity** and its **instantaneous velocity**.

Average velocity – The average of the velocity over a given time interval

Instantaneous velocity – The velocity at a given instant in time

So if you had a way of measuring the ball's velocity the very moment that it hit the floor, you would know its instantaneous velocity at that moment. You can measure that, but it requires some specialized equipment, like a radar gun. You didn't have that, so the best you could do is measure the ball's average velocity over the time it took to roll from the end of the ramp to the wall.

So in the experiment, the ball's instantaneous velocity was changing. It increased as it rolled down the ramp, and it decreased when it rolled across the floor. When an object's velocity changes, we say that the object is experiencing **acceleration**.

Acceleration – A change in an object's velocity

I will give you an equation for calculating acceleration in the next chapter. For right now, I just want you to concentrate on what the term means. You have probably used the term before, but as is often the case, physicists use it differently from most people. Most people think of acceleration as speeding up. In physics, acceleration is *any* change in an object's velocity. If an object is speeding up, it is accelerating, but if an object is slowing down, it is also accelerating. In your experiment, then, the ball was constantly experiencing acceleration. As the ball rolled down the ramp, the acceleration resulted in it speeding up. As it rolled across the floor, the acceleration resulted in the ball slowing down.

How can you tell whether acceleration slows an object down or speeds it up? It is based on direction. Like velocity, acceleration is a vector quantity, so it has a direction. In your experiment, the ball was rolling down the ramp, and the acceleration was pointing down the ramp. The direction of the acceleration was the same as the direction of the velocity, so the object sped up. When the ball started rolling on the floor, the velocity was in the direction of the wall, but the acceleration was in the opposite direction. As a result, the object slowed down. This is an important thing to remember.

When acceleration and velocity are in the same direction, an object's speed increases. When acceleration and velocity are in opposite directions, an object's speed decreases.

You will get more experience with this fact, as well as the distinction between instantaneous and average velocity, in the next section.

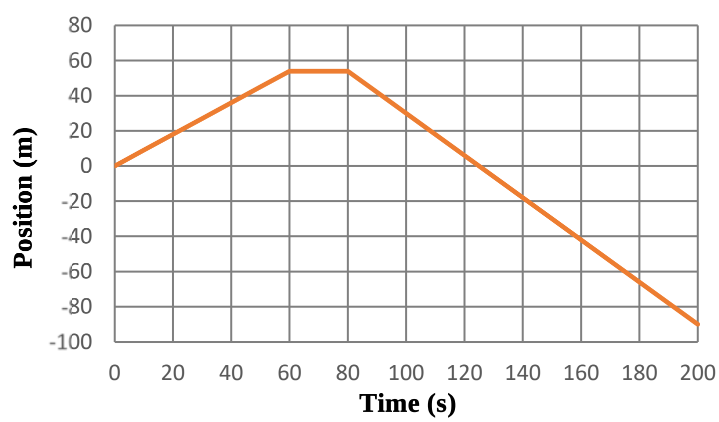
Comprehension Check

11. Suppose you did one more trial of the experiment, with the end of the ramp only 0.50 m away from the wall. Would the average velocity be greater than, less than, or the same as the velocity you measured when it was 1.00 m from the wall?

12. A policeman with a radar gun measures a car's instantaneous velocity to be 29 m/s west. Half a second later, he measures it to be 25 m/s west. What is the direction of the car's acceleration?

A Picture Is Worth a Thousand Words

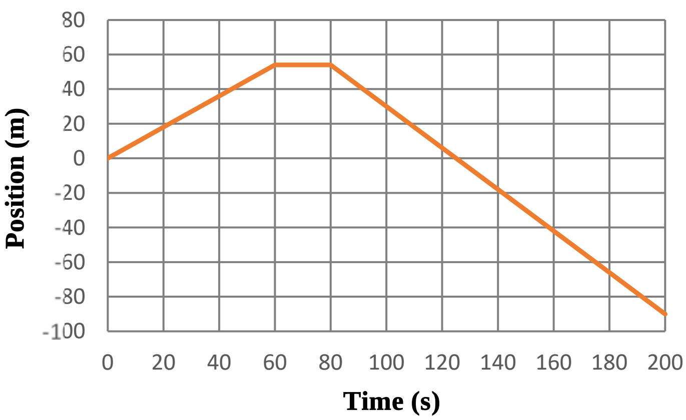
Physicists often use graphs to analyze situations, since they contain a lot of information. Consider, for example, the graph below. It is showing you the position of a ball rolling on a track relative to its starting position. For this graph, positive means north and negative means south. Notice that the ball begins rolling north, because its position gets larger and more positive. At 60 seconds, the ball's position stops changing, but then at 80 seconds, it starts decreasing. That means it is rolling back closer to its starting point, so it is now headed south. It keeps heading south, and at just over 120 seconds, its position is 0, which means it is back to its starting point. After that, the position keeps getting more and more negative, which means it keeps traveling south from its starting point.



But let's look at this graph in a lot more detail. First, remember how we calculate velocity. We take the change in position (the displacement) and divide it by the change in time. Think about how that relates to the graph. Position is on the y-axis of the graph, and time is on the x-axis. So the change in position is the change in the y-axis, which is often called the **rise** of the graph, and the change in time is the change in the x-axis, which is often called the **run** of the graph. So velocity is the rise of the graph divided by the run. Do you remember what that is? It's the **slope** of the graph. This is important.

The slope of a position versus time graph is the velocity.

Because I want to talk about the graph more, I copied it and put below so you can refer to it easily. First, let's make sure you can read the graph properly. Notice that the lines are pretty far apart, so you can estimate in between them. For example, notice where the graph levels out on the y-axis. It is between 40 m and 60 m, but it is much closer to 60 m than it is to 40 m. You can estimate between the lines and say that



it levels off at 55 m. You might go as low as 52 or as high as 58, but that's okay. The last significant figure is an estimate, so there is always error in it. Nevertheless, since you can estimate between the lines, the precision is generally one decimal place more than the labels on the graph. Thus, you can read the y-axis to the ones place. The same is true for the x-axis. Look at where the graph falls back down to 0 after it levels out. At what time does that happen? It's between 120 s and 140 s, but much closer to 120 s. I would say 123 s.

Now let's calculate the initial slope. At t = 0 seconds, the position is 0 meters. At t = $6.0\text{x}10^{1}$ s, seconds, the position is 55 meters. Why did I use scientific notation for the time? Remember that you can read the x-axis to the ones place, so the zero in 60 is significant. I must therefore report it in scientific notation to make it significant. From those two points, we can determine the slope. To do that, we take the y-value at the beginning and subtract it from the y-value at the end. We then divide that by the end time minus the beginning time:

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{55\text{ m} - 0\text{ m}}{6.0\times10^{1}\text{ s} - 0\text{ s}} = \frac{55\text{ m}}{6.0\times10^{1}\text{ s}} = 0.92\ \frac{\text{m}}{\text{s}}$$

Since both 55 m and 6.0×10^{1} s have two significant figures, the answer must have two. Thus, the average velocity of the ball during this time was 0.92 m/s.

There are a couple of important things to point out here. First, notice that the velocity is positive. This means the ball is rolling north, since north was defined as positive. Also, notice that over the time interval, the graph is a straight line. What do we know about straight lines? They have a *constant slope*. Thus, the slope would be the same no matter what time interval I used, as long as it was somewhere between 0 to 60 seconds. So if I calculated the slope from 15-25 seconds, it would still be 0.92 m/s. If I calculated it from 16 s to 17 s, it would be 0.92 m/s. What does that tell you? It tells you the average velocity and instantaneous velocity are the same during that time interval.

But what happens at 60 seconds? The slope changes. The graph becomes a horizontal line. What is the slope of a horizontal line? It's 0. Thus, the velocity changes from 0.92 m/s to 0 m/s. This tells you the ball experienced an acceleration at 60 seconds. What was the direction of the acceleration? The ball slowed down from 0.92 m/s north to zero, so the acceleration was opposite of the velocity. The velocity was north (because it was positive), so the acceleration was pointed south. See if you can reason like this by studying the following example and solving the problem that follows.

Example 1.7

In the graph shown above, what is the instantaneous velocity at 165 s?

Notice that the graph is a straight line from t = 80 s to t = 200 s. Thus, the velocity is constant, and the instantaneous velocity is the same as the average velocity, which is given by the slope of the line. I can choose any time interval between 80 s and 200 s, but I will use the entire interval. Remember, however, that what we read from the graph is precise to the ones place in each case, so I will have to use scientific notation for the times:

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{-89\ \text{m} - 55\ \text{m}}{2.0\times10^{2}\ \text{s} - 8.0\times10^{1}\ \text{s}} = \frac{-144\ \text{m}}{1.2\times10^{2}\ \text{s}} = -1.2\ \text{m/s}$$

Now remember, you might read the graph differently, or you might use a different time interval. Thus, your answer might be -1.0 m/s or maybe -1.4 m/s, but that's okay. There is always error in the last significant figure, so from a scientific standpoint, those are all the same answer. If you are having trouble understanding the scientific notation at the bottom of the fraction, just convert it into decimal for the purpose of doing the math, but then use the scientific notation to determine the significant figures. The bottom of the fraction is really 200 s – 80 s, which is 120 s. The scientific notation tells you that the first zero in 200 s is significant, and that's in the tens place. It also tells you the zero in 80s is significant, and it's in the ones place. Thus, the least precise number has its last significant figure in the tens place, so your answer must have its last significant figure in the tens place, which 1.2×10^{2} m/s does. Because it would still have two significant figures if you reported it as 120 m/s, that would be just as good an answer.

We already determined that acceleration occurred at t = 60 s. At what other time does it occur? In what direction is it then?

The graph changes slope again at 80 s, so the other acceleration occurs at 8.0×10^{1} s. At that time, the ball goes from a velocity of 0 m/s to a velocity of -1.2 m/s, which is 1.2 m/s south. Thus, it sped up going south. In order to speed up, acceleration and velocity must be in the same direction, so the acceleration is to the south.

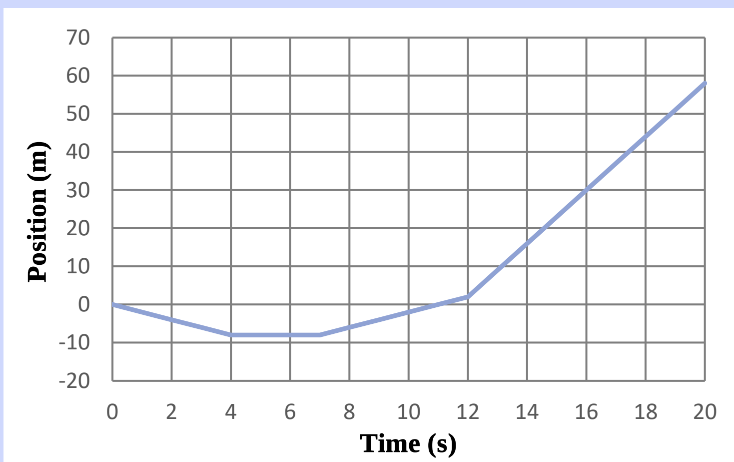
Comprehension Check

13. For the graph on the right, the positive direction is east.

a. Over what time interval is the velocity zero?

b. When does the object experience acceleration? For each acceleration, indicate the direction.

c. What is the instantaneous velocity at t = 11.0 seconds?



To Err Is Human

Before I finish this chapter, I need to go back to Experiment 1.4 for a moment. In that experiment, I had you measure the same thing (the time it took the ball to roll from the end of the ramp to the wall) five times and average the result. Why did I do that? To reduce **experimental error**. After all, you had to start the timer when the ball hit the floor and stop it when the ball hit the wall. Do you really think you started and stopped the timer at the right times? Probably not. You might have anticipated the ball rolling off the ramp, which would have caused you to start the timer too soon. You might have heard the ball hit the wall but not immediately stopped the timer, causing the timer to stop late. Both of those actions would cause the time measured to be too long. If you were late when the ball rolled off and early when it hit the wall, the measured time would be too short. Indeed, had you been perfect each time, all five measurements would have been the same. Were they? Probably not.

Since we all make errors when we make measurements, we need some way to reduce the effect of those errors. Well, assuming you didn't make the same mistakes each time you made the measurements, some of your times would have been too long, while others would have been too short. By averaging the measurements, you can make these mistakes "cancel out," so that the average is a bit more accurate than any given measurement. The more times you make the measurement, the more accurate the average becomes. Thus, had you made ten measurements and averaged them, you would have an even more accurate average. Depending on the difficulty of the measurement and how accurate you want to be, you might do a lot more than ten. Of course, the more measurements you do, the longer the experiment takes, so there is a tradeoff. In the experiments you will do for this course, five measurements will be considered a pretty good compromise between accuracy and the time it takes to do the experiment.

In fact, this is why significant figures are so important. They give you an idea of how well you know the result. Because of the many sources of error, and because each measurement is limited by the instrument with which you make the measurement, the last significant figure always has error in it. Thus, if you end up with an answer that is different from someone else's but only in the last significant figure, it is really impossible to tell which answer is correct. Thus, we say that the answers are consistent with one another. Had you solved the first part of Example 1.7 and gotten an answer of -1.4 m/s or -1.0 m/s, it would be considered just as correct as the answer given above: -1.2 m/s, because there is always error in the last significant figure.

You have to be careful, however. This kind of reasoning applies only to **random errors**, which cause the result to sometimes be larger and sometimes be smaller than the actual answer. There are also **systematic errors**, which cause the result to be wrong in the same way all the time. Suppose your timer wasn't working properly and always measured a time that was shorter than the actual time. That would be a systematic error, and no amount of averaging will get rid of that.

Because there are so many sources of error in experiments, and because science is fundamentally based on experiments, you have to understand that anything we learn in science has the possibility of being wrong, since the experiments we base our learning on can contain systematic errors. As a result:

Science cannot prove anything.

Science can produce a lot of evidence that can allow you to believe something with a lot of confidence, but that doesn't mean it's absolutely true. For example, even though Newton's Laws (the first of which you've already learned) have an *enormous* amount of evidence to back them up, we don't know for certain that they are true, because the evidence is based on experiments, which might all be in error. In fact, we already know that Newton's Laws are not true when we deal with atoms and molecules. Thus, please understand that while science is incredibly useful and can allow you to learn a lot about God's creation, it is not a source of absolute truth!

Sample Calculations for Experiment 1.4

Times it took for the ball to roll 1.50 m: 1.67 s, 1.81 s, 1.79 s, 1.88 s, 1.61 s
Times it took for the ball to roll 1.00 m: 0.84 s, 0.80 s, 0.91 s, 0.87 s, 0.81 s

Average time it took to roll 1.50 m: (1.67 s + 1.81 s + 1.79 s + 1.88 s + 1.61 s) ÷ 5 = 8.76 s ÷ 5 = 1.75 s

Significant figures explanation: When you add numbers, you look at decimal place. Each time has its last significant figure in the hundredths place, so the answer must as well. That's why it is 8.76 s.

When you divide, you count significant figures. 8.76 s has three, but the 5 is exact, because you performed exactly 5 trials, so it has infinite significant figures. That means the lowest number of significant figures is three, so the answer must have three. That's why it is 1.75 s

Velocity as it rolled 1.50 m: 1.50 m ÷ 1.75 s = 0.857 m/s

Significant figures explanation: When you divide, you count significant figures. 1.50 m has three, as does 1.75 s, so the answer must have three as well. That's why it is 0.857 m/s.

Average time it took to roll 1.00 m: (0.84 s + 0.80 s + 0.91 s + 0.87 s + 0.81 s) ÷ 5 = 4.23 s ÷ 5 = 0.846 s

Significant figures explanation is the same as for the first average.

Velocity as it rolled 1.00 m: 1.00 m ÷ 0.846 s = 1.18 m/s

Significant figures explanation is the same as for the velocity.

Solutions to the "Comprehension Check" Questions

1. We need to divide the numbers.

$$\text{Density} = 3.40\times10^{2}\ \text{g} \div 1.215\times10^{-4}\ \text{m}^{3} = 2.798353\times10^{6}\ \frac{\text{g}}{\text{m}^{3}}$$

You should learn how to input scientific notation into your calculator, since you will have to do that later on. For now, however, you could just convert to their decimal equivalents (340 g and 0.0001215 m^3) and put those numbers into your calculator. Remember, however, that 3.40×10^{2} g has three significant figures, while 1.215×10^{-4} m^3 has four. In multiplication and division, you report your answer with the least number of significant figures. Thus, the answer is $\underline{2.80\times10^{6}\ \text{g/m}^{3}}$. Notice that the unit, which must be included in the answer, is determined like using variables in algebra. Since x ÷ y = x/y, g ÷ m^3 = g/m^3.

2. We start by getting the conversion relationship. Since "m" means "milli," which is 0.001:

$$1\ \text{mg} = 0.001\ \text{g}$$

Notice how the left side of the conversion relationship contains the unit with the prefix (mg), while the right side has the prefix's definition (0.001) followed by the base unit (g). Now we put the original measurement over 1 to make it a fraction and multiply by the conversion relationship so that g cancels:

$$\frac{0.0231\ \cancel{\text{g}}}{1} \times \frac{1\ \text{mg}}{0.001\ \cancel{\text{g}}} = 23.1\ \text{mg}$$

Since the original measurement has three significant figures and conversion relationships have infinite significant figures, the answer must have three. That's why the answer is <u>23.1 mg</u>.

3. We start by defining a direction. I will define west as positive, which makes east negative. Thus, the first part of his trip results in a displacement of 570 m, while the second part gives a displacement of -310 m. That means

$$\text{Total Displacement} = 570\ \text{m} + -310\ \text{m} = \underline{260\ \text{m}}$$

Since I defined west as positive, that answer is good enough, because it means 260 m west. Had you defined east as positive, your answer would have been -260 m, which would also mean 260 m west. From a significant figures point of view, both numbers have their last significant figure in the tens place (the zeroes are not significant because they are not to the right of the decimal), so the answer must also have its last significant figure in the tens place, which it does.

4. Speed is the change in *distance* over the change in time. The total distance traveled was:

$$\text{Total Distance} = 4.61\ \text{km} + 4.92\ \text{km} = 9.53\ \text{km}$$

$$\text{speed} = \frac{\Delta d}{\Delta t} = \frac{9.53\ \text{km}}{0.732\ \text{hr}} = 13.0\ \frac{\text{km}}{\text{hr}}$$

Notice that since both distances have their last significant figure in the hundredths place, the total distance must have its last significant figure in the hundredths place. When calculating speed, however, we are dividing, so we count significant figures. Both 9.53 km and 0.732 hr have three significant figures, so the answer must have three. Thus, 13 km/hr is not correct. It is <u>13.0 km/hr</u>.

On the other hand, velocity is the change in *displacement* over the change in time. So we must first determine displacement, which requires defining a direction. I will define east as positive.

$$\text{Total Displacement} = 4.61\text{ km} + -4.92\text{ km} = -0.31\text{ km}$$

$$\mathbf{v} = \frac{\Delta\mathbf{x}}{\Delta t} = \frac{-0.31\text{ km}}{0.732\text{ hr}} = -0.42\,\frac{\text{km}}{\text{hr}}$$

That means his velocity was <u>-0.42 km/hr</u>, which could also be reported as 0.42 km/hr west. Once again, both displacements had their last significant figure in the hundredths place, so the sum must have its last significant figure in the hundredths place. However, when you divide, you count significant figures. Since 0.31 km has only two significant figures, the velocity can have only two.

5. Relative to the runner in the lead means we are going to treat the lead runner as the reference. Defining westward motion as positive, then, both runners have positive velocities.

$$\text{Relative velocity} = \text{Velocity of moving object} - \text{Velocity of reference object}$$

$$\text{Relative velocity} = 2.8\,\frac{\text{m}}{\text{s}} - 2.9\,\frac{\text{m}}{\text{s}} = -0.1\,\frac{\text{m}}{\text{s}}$$

Since we are subtracting and both numbers have their last significant figure in the tenths place, the answer must be reported to the tenths place as well. Thus, relative to the lead runner, the second-place runner has a velocity of <u>0.1 m/s east</u>. In other words, the second-place runner is moving away from the lead runner. Once again, since we defined direction, we could have just left the answer as -0.1 m/s.

6. The first thing we should notice is that the time unit in the velocity is seconds, but the time is given in minutes. Thus, we must convert.

$$\frac{4.0\,\cancel{\text{min}}}{1} \times \frac{60\text{ s}}{1\,\cancel{\text{min}}} = 240\text{ s}$$

Remember, conversion factors are exact, so they have an infinite number of significant figures. That means we are limited to two significant figures because of the 4.0 min. Now we can use Equation (1.2), defining east as positive:

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

$$3.45\,\frac{\text{m}}{\text{s}} = \frac{\Delta\mathbf{x}}{240\text{ s}}$$

We can now use algebra to solve for Δx:

$$\Delta\mathbf{x} = 3.45\,\frac{\text{m}}{\cancel{\text{s}}} \times 240\,\cancel{\text{s}} = 830\text{ m}$$

Since east was defined as positive, the displacement is <u>830 m east</u>.

7. Even though both trains are moving, we can treat one as sitting still, and the other as traveling with the trains' relative velocity. Let's treat the eastbound train as stationary, and let's define west as positive. That makes the eastbound train's velocity negative, and the other train's velocity positive:

$$\text{Relative velocity} = \text{Velocity of moving object} - \text{Velocity of reference object}$$

$$\text{Relative velocity} = 19\,\frac{\text{m}}{\text{s}} - -23\,\frac{\text{m}}{\text{s}} = 42\,\frac{\text{m}}{\text{s}}$$

So this situation is equivalent to the eastbound train car sitting still, and the other train approaching it at a velocity of 42 m/s west. To collide, then, the westbound train must experience a displacement of 16.5 km in the positive direction (west). That's not consistent with the unit in velocity, however, so we need to convert:

$$\frac{16.5\,\cancel{\text{km}}}{1} \times \frac{1{,}000\text{ m}}{1\,\cancel{\text{km}}} = 16{,}500\,m$$

Now we can use Equation (1.2):

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

$$42\,\frac{\text{m}}{\text{s}} = \frac{16{,}500\text{ m}}{\Delta\text{t}}$$

We can now use algebra to solve for Δt:

$$\Delta\text{t} = \frac{16{,}500\,\cancel{\text{m}}}{42\,\frac{\cancel{\text{m}}}{\text{s}}} = \underline{390\text{ s}}$$

8. <u>You will travel upwards</u>. You were originally coasting along with the plane. When the plane suddenly dropped, you continued to move with the velocity you had, so you didn't drop with it. A seat belt would have exerted a force on you to make you drop with the plane. However, without the seat belt, you didn't drop with the plane, so you moved upwards relative to the seat. This actually happened to me once. The pilot said that we hit a pocket of low pressure. Fortunately, I was wearing my seatbelt.

9. <u>Block A experienced a weaker frictional force</u>. Without friction, they would move forever. Thus, the one that traveled farther was closer to having no friction, so it had weaker friction.

10. <u>It will land in the back of the truck, at the same place from which you shot it</u>. The arrow has the truck's velocity when it is shot, so it will keep that velocity. As long as the truck's velocity stays constant, then, it will simply keep up with the truck as the force from the bow causes its upward velocity to increase and then gravity takes over, slowing the arrow and then making it fall. However, there is no force fighting against or aiding the velocity it had with the truck, so the arrow keeps that velocity during its entire flight.

11. <u>The average velocity would be greater</u>. Since it doesn't roll as far, friction can't slow it down as much, so on average, the velocity will be greater.

12. <u>The acceleration is east</u>. The speed is the scalar quantity, and it decreased from 29 m/s to 25 m/s. That means velocity and acceleration are in opposite directions.

13. a. <u>From 4.0-7.0 seconds</u>, the line is horizontal, which means zero slope and thus zero velocity.

b. <u>At 4.0 seconds, the acceleration is east. At 7.0 seconds, it is east, and at 12.0 seconds, it is east</u>. Remember that the slope tells you the velocity. You can calculate them all of you want, but you don't need to. Rising graphs have positive slopes, and the steeper the rise, the more positive. Falling graphs have negative slope, and the steeper the fall, the more negative. So the velocity is negative from 0 s to 4 s, which means the velocity is west. It then goes to zero. That means it slowed down. If it was traveling west and slowed down, the acceleration is east. At 7 s, the velocity goes from zero to something positive, because the graph is rising. Thus, the velocity increased in the positive direction, which means the acceleration is in the positive direction as well. So that means the acceleration is east. At 12 s, it got steeper, which means more positive. That means the positive velocity increased, which tells you the acceleration was positive.

c. From 7 s to 12 s, the graph is a straight line, so its slope is the same everywhere. That means you can choose any interval from 7 s to 12 s for calculating the slope. I will choose the entire interval, but you can choose differently if you want.

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{2\text{ m} - -8\text{ m}}{12.0\text{ s} - 7.0\text{ s}} = \frac{1.0{\times}10^{1}\text{ m}}{5.0\text{ s}} = 2.0\text{ m/s}$$

That means 2.0 m/s east. Since the sign of the direction is given by the problem, you can also report the answer as 2.0 m/s, since the positive means east.

For significant figures, remember that you can estimate between the lines to get one more decimal place than the label. Thus, you can read the y-axis to the ones place and the x-axis to the tenths place. When you subtract, you look at decimal place. The distances both have their last significant figure in the ones place, so the difference must as well. Thus, you must report the answer (10 m) so that the zero is significant. The only way to do that is with scientific notation. The times both have their last significant figure in the tenths place, so the answer must as well. When you divide, you count significant figures. Since both the distance and time have two, the answer should have two as well.

Review

1. Define the following terms:

a. Vector quantity
b. Scalar Quantity
c. Friction
d. Inertia
e. Average velocity
f. Instantaneous velocity
g. Acceleration

2. You see the following entries in a lab notebook. Indicate what physical quantity was measured in each case:

a. 17 m/s
b. 12 inches
c. 1.2 km north
d. 25 seconds
e. 22 miles/hr west

3. You ride your bicycle for 5.2 km west and then turn around and ride it 4.3 km east. What is the total distance you traveled? What is the total displacement?

4. Suppose you took 925 seconds to make the trip discussed in problem #3. What was your average speed? What was your average velocity?

5. A car is on a highway, traveling at 25 m/s west. A truck is on the same highway, traveling 29 m/s west. What is the velocity of the car relative to the truck? What is the velocity of the truck relative to the car? If the two vehicles eventually collide, which one was ahead?

6. You are walking with a constant velocity of 1.5 m/s north. If you walk for 15 minutes, what will be your displacement?

7. You ride your bicycle with a velocity of 11 m/s west. If you do that until your displacement is 7.8 km west, how long will it take you?

8. Two cars start next to one another on a road. One travels at 31 m/s north, while the other travels at 28 m/s south. How far will they be from each other in 22 minutes?

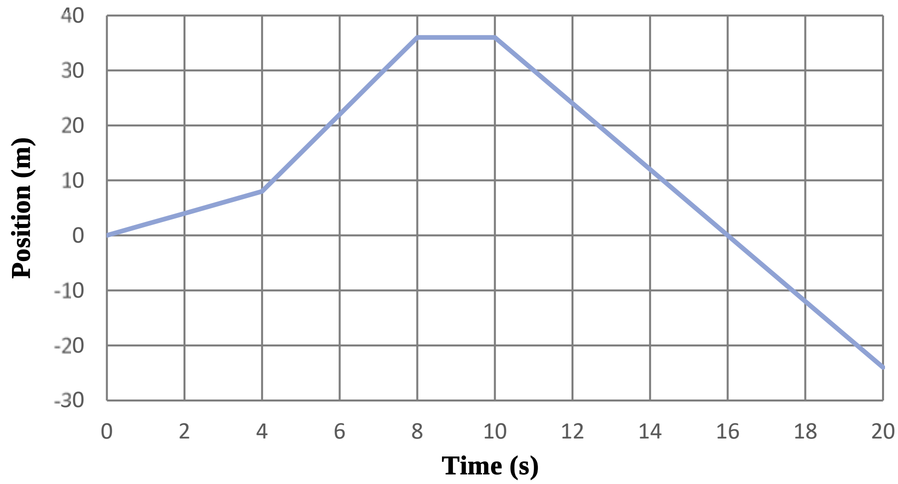
9. A car is traveling at a constant velocity. Is there a net force acting on it? How would your answer change if you only knew it was traveling at a constant speed?

10. A man is riding a horse with a constant velocity, when suddenly, the horse plants its feet and stops. When that happens, how will the man move relative to the horse?

11. You are told that object A has much more inertia than object B. If they are both traveling with the same velocity, which will be harder to stop?

12. A moving object is experiencing a net force. Is it accelerating or not?

Questions 13-17 refer to the graph below, for which the positive direction is east.



13. At what times does the object in the graph experience an acceleration? What direction is that acceleration?

14. During what time interval is the object not moving?

15. During what time interval is the object east of its starting position? For what time interval is it west of its starting position?

16. Are the instantaneous and average velocities the same from 2 seconds to 6 seconds? What about from 14 seconds to 18 seconds?

17. What is the instantaneous velocity at 1 second?

18. An experiment has only random errors in it. One student performs it ten times and averages her results. The other does it just one time and reports the result as his final answer. Most likely, which student will be more accurate?

19. How would your answer to #18 change if the experiment had systematic errors in it?

Ignoring air resistance, this skydiver is in free fall.