WELCOME

When you look around, do you ever wonder where everything came from and how it was made? Have you ever contemplated why a tree is hard, a sponge is soft, and a breeze is invisible?

> By faith we understand that the universe was formed at God's command, so that what is seen was not made out of what was visible.
> —Hebrews 11:3, NIV

first reactions

What do you see when you look at the periodic table of elements? At first glance, most students see so many scientific symbols that they become intimidated. But the periodic table is the essence of chemistry. The years of discovery and knowledge summarized in it make it unlike any other common science tool.

From the galaxies in the universe to the tiniest microscopic cell, you experience the elements wherever you look!

Welcome to the world of chemistry! This year you are going to take a journey that allows you to explore God's creation with the eyes of a scientist. Studying God's creation at the molecular and atomic level can enable you to understand how wonderfully everything fits together in this world God has created for us.

> How many are your works, Lord! In wisdom you made them all; the earth is full of your creatures.
> —Psalm 104:24, NIV

Science is the endeavor of explaining the truth of the world around us, and God is the source of both creation and truth. You will discover that proper application of scientific principles will help you uncover how the world around you operates. Since science and faith both search for truth, they complement each other. The more you know about your world, the more you will wonder at the complex beauty of God's creation.

> He has made everything beautiful in its time. He has also set eternity in the human heart; yet no one can fathom what God has done from beginning to end.
> —Ecclesiastes 3:11, NIV

God gave humans dominion over the earth, so we can understand many things about it. This textbook is not just a compilation of facts and figures for you to memorize. This textbook is designed to take you on a remarkable journey that involves facts about chemistry, figures to help you understand the facts, and truth from your Creator. We at Apologia pray that this text will enable you to say:

> "How great are your works, LORD, how profound your thoughts!"
> —Psalm 92:5, NIV

MEASUREMENT, UNITS, AND THE SCIENTIFIC METHOD

Our understanding of life has changed more in the past 2 centuries than all the previously recorded span of human history. The earth's population has increased more than 5-fold since 1800, and our life expectancy has nearly doubled because of our ability to synthesize medicines, control diseases, and increase crop yields. Many goods are now made of polymers (plastics) and ceramics instead of wood and metal because of our ability to manipulate and manufacture materials with properties unlike any found in nature. In one way or another, all of these changes involve **chemistry**.

first reactions

When God told Noah to build an ark 300 cubits long, Noah had to know how long a cubit was in order to succeed. Imagine if Noah had built an ark 300 inches long! As you begin to learn the foundational language of chemistry, keep in mind that it is only the very beginning of true understanding.

What is chemistry? Quite simply, chemistry is the study of **matter**. Of course, this definition doesn't do us much good unless we know what matter is. So, to understand what chemistry is, we first need to define matter.

Matter—Anything that has mass and takes up space.

If matter is defined in this way, almost *everything* around us is matter. Your family car has a lot of mass. That's why it's so heavy. It also takes up a lot of space in the driveway or the garage. Your car must be made of matter. The food you eat isn't as heavy as a car, but it still has some mass. It also takes up space. So food must be made up of matter as well. Indeed, almost everything you see around you is made up of matter because nearly everything has mass and takes up space. There is one thing that has no mass and takes up no space. It's all around you right now. Can you think of what it might be?

You might think that the answer is air. However, that's not the right answer. Perform experiments 1.1 and 1.2 to see what we mean.

EXPERIMENT 1.1

PURPOSE: To determine if air has mass.

MATERIALS:
- Meterstick (A yardstick will work as well, but a 12-inch ruler is not long enough.)
- Two 8-inch or larger balloons
- 2 pieces of string long enough to tie the balloons to the meterstick
- Tape
- Safety goggles

QUESTION: Does air have mass?

HYPOTHESIS: Pick one: Either air has mass or air does not have mass.

PROCEDURE:
1. Without blowing them up, tie the balloons to the strings. Be sure to make the knots loose so that you can untie one of the balloons later in the experiment.
2. Tie the other end of each string to an end of the meterstick. Try to attach the strings as close to the ends of the meterstick as possible.
3. Once the strings have been tied to the meterstick, tape them down so that they cannot move.
4. Go into your bathroom and pull back the shower curtain so that a large portion of the curtain rod is bare. Balance the meterstick (with the balloons attached) on the bare part of the shower curtain rod. You should be able to balance it very well. If you don't have a shower curtain rod or you are having trouble using yours, you can use any surface that is adequate for delicate balancing like the upper part of a chair.
5. Once you have the meterstick balanced, stand back and look at it. The meterstick balances now because the total mass on one side equals the total mass on the other side. To knock it off balance, you would need to move the meterstick or add more mass to one side. You will do the latter.
6. Have someone else hold the meterstick so that it does not move. For this experiment to work properly, the meterstick must stay stationary.
7. While the meterstick is held stationary, remove one of the balloons from its string (do not untie the string from the meterstick), and blow up the balloon.
8. Tie the balloon closed so that the air does not escape, then reattach it to its string.
9. Have the person holding the meterstick let go. If the meterstick was not moved while you were blowing up the balloon, it will tilt toward the side with the inflated balloon as soon as the person lets it go. This is because you added air to the balloon. Since air has mass, it knocks the meterstick off balance. So air does have mass!
10. Clean up and return everything to the proper place.

CONCLUSION: What did you think? Write something about what you observed related to the fact that air has mass.

EXPERIMENT 1.2

PURPOSE: To determine if air takes up space.

MATERIALS:

- Tall glass
- Paper towel
- Sink full of water
- Safety goggles

QUESTION: Does air take up space?

HYPOTHESIS: Pick one: Either air takes up space or air does not take up space.

PROCEDURE:

1. Fill the sink with water until the water level is high enough to submerge the entire glass.
2. Make sure the inside of the glass is dry.
3. Wad up the paper towel and shove it down into the bottom of the glass.
4. Turn the glass upside down and be sure that the paper towel does not fall out of the glass.
5. Submerge the glass upside down in the water, being careful not to tip the glass at any time.
6. Wait a few seconds and remove the glass, still being careful not to tilt it.
7. Pull the paper towel out of the glass. You will find that the paper towel is completely dry. Even though the glass was submerged in water, the paper towel never got wet. Why? When you tipped the glass upside down, there was air inside the glass. When you submerged it in the water, the air could not escape the glass, so the glass was still full of air. Since air takes up space, there was no room for water to enter the glass, so the paper towel stayed dry.
8. Repeat the experiment, but this time be sure to tip the glass while it is underwater. You will see large bubbles rise to the surface of the water. When you pull the glass out, you will find that it has water in it and that the paper towel is wet. This is because tilting the glass allowed the air trapped inside it to escape. Once the air escaped, there was room for the water to come into the glass.
9. Clean up and return everything to the proper place.

CONCLUSION: What did you think? Write something about what you observed related to the fact that air takes up space.

think about this

Air is typically used as a metaphor for nothingness. It is, however, very complex. Aristotle (384–322 BC) is generally given credit for being the first to state that air has weight, although many did not believe him. Would it surprise you to know that some 1,400 years *before* Aristotle, it was known that air had weight? It's true. The Bible tells us that God "gave to the wind its weight and apportioned the waters by measure" (Job 28:25). Think about this verse in the context of the timeline of scientific knowledge. Job may have lived anywhere from 2300 to 1700 BC. God created everything visible and invisible, including air. The Bible is His word, and we can trust it to be true. We explore science to understand what God already knows about His creation.

Now that you see that air does have mass and does take up space, have you figured out the correct answer to our original question? What very common thing that is surrounding you right now has no mass and takes up no space? The answer is light. As far as scientists can tell, light does not have any mass and takes up no space. Light is not considered matter. Instead, it is pure energy. Everything else that you see around you is considered matter. Chemistry, then, is the study of nearly everything! As you can imagine, studying nearly everything can be a very daunting task. However, chemists have found that even though there are many forms of matter, they all behave according to a few fundamental laws. If we can clearly understand these laws, then we can clearly understand the nature of the matter that exists in God's creation.

Before we start trying to understand these laws, we must step back and ask a more fundamental question: *How* do we study matter? The first thing we have to be able to do in order to study matter is to measure it. If we want to study an object, we first must learn things like how big it is, how heavy it is, and how old it is. To learn these things, we have to make some measurements. The rest of this module explains how scientists measure things and what those measurements mean.

UNITS OF MEASUREMENT

Let's suppose you are making curtains for a friend's windows. You ask him to measure the window and give you the dimensions so that you can make the curtains the right size. Your friend tells you that his windows are 50 by 60, so that's how big you make the curtains. When you go over to his house, it turns out that your curtains are more than twice as big as his windows! Your friend tells you that he's certain he measured the windows correctly, and you tell your friend that you are certain you measured the curtains correctly.

How can this be? The answer is quite simple. Your friend measured the windows in centimeters. You, on the other hand, measured the curtains in inches. The problem was not caused by measuring incorrectly. Instead, the problem was the result of measuring with different **units**.

think about this

"Who has measured the waters in the hollow of his hand and marked off the heavens with a span, enclosed the dust of the earth in a measure and weighed the mountains in scales and the hills in a balance?" Isaiah 40:12

Can you determine what the author is trying to do here? He is trying to describe the greatness of God by using measurements that would have been understood by anyone living at this time. How would scientists of this day try to describe the greatness of God?

When we are making measurements, the units we use are just as important as the numbers that we get. If your friend had told you that his windows were 50 centimeters by 60 centimeters, there would have been no problem. You would have known exactly how big to make the curtains. Since he failed to do this, the numbers that he gave you (50 by 60) were useless. A failure to indicate the units involved in measurements can lead to serious problems. For example, the Mars Climate Orbiter, a NASA (National Aeronautics and Space Administration) spacecraft built for the exploration of Mars, vanished during an attempt to put it into orbit around the planet. In an investigation that followed, NASA determined that a mix-up in units had caused the disaster. One team of engineers had used metric units in its calculations, while another team had used English units in executing an engine burn. The teams did not indicate the units they were using, and as a result, we lost a spacecraft worth several billion dollars.

Scientists should never simply report numbers. They must always include units so that everyone knows exactly what the numbers mean. That will be the rule in this chemistry course.

If you answer a question or solve a problem and do not list units with the numbers, your answer will be considered incorrect.

FIGURE 1.1
Two Consequences of Not Using Units Properly
Window illustration by David Weiss. Mars Climate Orbiter image courtesy of NASA/JPL/Caltech

These curtains are too long for this window because the window was measured in centimeters, but the curtains were made assuming the measurements were in inches.

The Mars Climate Orbiter did not successfully make it into orbit because 2 engineering teams involved used different units in their designs.

Since scientists use units in all of their measurements, it is convenient to define a standard set of units that will be used by everyone. This system of standard units is called the metric system. If you do not fully understand the metric system, don't worry. By the end of this module, you will be an expert at using it. If you do fully understand the metric system, you can skim this section as a review.

THE METRIC SYSTEM

We need to measure many different things when studying matter. First, we must determine how much matter exists in the object that we want to study. We know that there is a lot more matter in a car than there is in a feather because a car is heavier. To study an object precisely, we need to know exactly how much matter is in it. To accomplish this, we need to measure mass and the amount of space the object takes up. So how do we measure the object's mass? In the metric system, the unit for mass is the **gram**. If an object has a mass of 10 grams, we know that it has 10 times the matter in an object with a mass of 1 gram. To give you an idea of the size of a gram, the average mass of a housefly is about 1 gram. A gram is a rather small unit. Most of the things that we will measure will have masses of 10 to 10,000 grams. For example, this book has a mass of about 2,300 grams.

Now that we know what the metric unit for mass is, we need to know a little more about the concept of mass. Some people might think of mass as weight. That's not exactly true. Mass and weight are 2 different measurements. **Mass** measures how much matter exists in an object. **Weight**, on the other hand, measures how hard gravity pulls on that object.

For example, if I were to use my bathroom scale and weigh myself, I would find that I weigh 150 pounds. However, if I were to take that scale to the moon and weigh myself, I would find that I weigh only 25 pounds. Does that mean I'm thinner on the moon than I am at home? Of course not. It means that on the moon, gravity is not as strong as it is in my house on Earth.

On the other hand, if I were to measure my mass at home, I would find it to be 68,000 grams. If I were to measure my mass on the moon, it would still be 68,000 grams. That's the difference between mass and weight. Since weight is a measure of how hard gravity pulls, an object weighs different amounts depending on the gravity that is present. Because mass measures how much matter is in an object, it does not depend on the gravity present.

Unfortunately, there are many other unit systems in use today besides the metric system. In fact, the metric system is probably not the system with which you are most familiar. You are probably most familiar with the English system. The English unit for mass is (believe it or not) called the **slug**. Although we will not use the slug often, it is important to understand what it means, especially when you study physics. The English system uses pounds as a measurement of how much material an object has. However, pounds are not a measure of mass; they are a measure of weight. The metric unit for weight is called the **Newton**.

There is more to measurements than mass, however. We might also want to measure how big an object is. For this, we must use the metric system's unit for distance, the **meter**. You are probably familiar with a yardstick. A meter is slightly longer than a yardstick. The English unit for distance is the foot. There are many other units of distance like inches, yards, and miles, but we'll talk about those a little later.

We also need to be able to measure how much space an object occupies. This measurement is commonly called **volume** and is measured in the metric system with the unit called the **liter**. The main unit for measuring volume in the English system is the **gallon**. To give you an idea of the size of a liter, it takes just under 4 liters to make a gallon.

Finally, we have to be able to measure the passage of time. When studying matter, we will see that it has the ability to change. The shape, size, and chemical properties of certain substances change over time. It is important to be able to measure time so that we can determine how quickly the changes take place. In both the English and metric systems, time is measured in **seconds**. That is a good thing, isn't it? We know of only one way to measure time!

Since it is very important for you to be able to recognize which units correspond to which measurements, table 1.1 summarizes what you have just read. The letters in parentheses are the commonly used abbreviations for the units listed. You should memorize this table.

TABLE 1.1
Physical Quantities and Their Base Units

Physical Quantity	Base Metric Unit	Base English Unit
Mass	gram (g)	slug (sl)
Distance	meter (m)	foot (ft)
Volume	liter (L)	gallon (gal)
Time	second (s)	second (s)

MANIPULATING UNITS

Let's suppose we asked you to measure the width of your home's kitchen using the English system. What unit would you use? Most likely, you would express your measurement in feet. However, suppose instead we asked you to measure the diameter of a penny. Would you still use the foot as your measurement unit? Probably not. Since you know the English system already, you would probably recognize that inches are also a unit for distance; since a penny is relatively small, you would use inches instead of feet. In the same way, if we asked you to measure the distance between 2 cities, you would probably express your measurement in terms of miles, not feet. This is why we used the term *base English unit* in table 1.1. Even though the English system's normal unit for distance is the foot, there are alternative units for length when measuring very short or very long distances. The same holds true for other English units. For example, volume can be measured in cups, pints, and ounces. We choose the unit based on the object to be measured.

The metric system also has alternative units for measuring small things compared to measuring big things. These alternative units are constructed by placing a prefix in front of the metric base unit. You will soon see the metric system is easier to use and understand than the English system because the prefixes always have the same relationship to the base unit, regardless of what measurement is used.

To use a larger or smaller scale in the metric system, simply add a prefix to the base unit. For example, in the metric system, the prefix *centi-* means one-hundredth, or 0.01. So, if we wanted to measure the length of a sewing needle in the metric system, we would probably express the measurement with the *centi*meter unit. Since a centimeter is one-hundredth of a meter, it can be used to measure relatively small things. On the other hand, the prefix *kilo-* means 1,000. If we want to measure the distance between 2 states, we would probably use the *kilo*meter. Since each kilometer is 1,000 times longer than the meter, it can be used to measure long things.

The beauty of the metric system is that these prefixes mean the same thing *regardless of the physical quantity being measured!* If we were measuring something with a very large mass (such as a car or boat), then we would use the kilogram unit. One kilogram is the same as 1,000 grams. In the same way, if we were measuring something that had a large volume, we might use the kiloliter, which is 1,000 liters. Adding a *kilo-* prefix to a unit multiplies the scale of the unit by 1,000—that is, 1,000 times larger than the base unit scale.

Compare this incredibly logical system of units to the chaotic English system. If we want to measure something short, we use the inch unit, which is equal to one-twelfth of a foot. On the other hand, if we want to measure something with small volume, we might use the quart unit, which is equal to one-fourth of a gallon. In the English system, every alternative unit has a different relationship to the base unit, and we must remember all of those crazy numbers. We have to remember that there are 12 inches in a foot, 3 feet in a yard, and 5,280 feet in a mile, while at the same time remembering that for volume there are 8 ounces in a cup, 2 cups in a pint, 2 pints in a quart, and 4 quarts in a gallon. That's a lot to memorize! Thankfully, the majority of science operates around the metric system.

In the metric system, all we have to remember is what the prefix means. Since the *centi-* prefix means one-hundredth, then we know that 1 centimeter is one-hundredth of a meter, 1 centiliter is one-hundredth of a liter, and 1 centigram is one-hundredth a gram. Since the *kilo-* prefix means 1,000, we know that there are 1,000 meters in a kilometer, 1,000 grams in a kilogram, and 1,000 liters in a kiloliter. Doesn't that make a lot more sense?

Another advantage to the metric system is that the prefixes are all based on a factor of 10. Table 1.2 summarizes the most commonly used prefixes and their numerical meanings. The prefixes in boldface type are the ones that we will use over and over again. Memorize those 3 prefixes and their meanings before you take the test for this module. The commonly used abbreviations for these prefixes are listed in parentheses.

TABLE 1.2
Common Prefixes Used in the Metric System

Prefix	Numerical Meaning
micro (μ)	0.00001
milli (m)	**0.001**
centi (c)	**0.01**
deci (d)	0.1
deca (D)	10
hecta (H)	100
kilo (k)	**1,000**
mega (M)	1,000,000

Remember that each of these prefixes, when added to a base unit, makes an alternative scale for measurement. If you wanted to measure the length of something small, you would have all sorts of options for which unit to use. If you wanted to measure the length of someone's foot, you could use the decimeter. Since the decimeter is one-tenth of a meter, it measures things that are only slightly smaller than a meter. On the other hand, if you wanted to measure the length of a sewing needle, you could use the centimeter because a sewing needle is significantly smaller than a meter. Or if you want to measure the thickness of a piece of paper, you might use the millimeter since it is one-thousandth of a meter, which is a *really* small unit.

You can see that the metric system is much more logical and versatile than the English system. That is, in part, why scientists and most countries in the world use it as their main system of measurement. With the exception of the United States, almost every country in the world uses the metric system as its standard system of units. Since scientists in the United States frequently work with scientists from other countries around the world, they must use and understand the metric system. Throughout all of the modules of this chemistry course, the English system of measurement will be presented only for illustration purposes. Since scientists must thoroughly understand the metric system, it will be the main system of units that we will use.

CONVERTING BETWEEN UNITS

Now that you understand what prefixes are and how they are used in the metric system, you must become familiar with converting between units within the metric system. In other words, if you measure the length of an object in centimeters, you should also be able to convert your answer to any other distance unit. For example, if you measure the length of a sewing needle in centimeters, you should be able to convert that length to millimeters, decimeters, meters, etc. Accomplishing this task is relatively simple as long as you remember the skills you learned in multiplying fractions. Suppose we asked you to complete the following problem:

$$\frac{7}{64} \times \frac{64}{13} =$$

There are 2 ways to figure out the answer. The first way would be to multiply the numerators and the denominators together and then simplify the fraction. If you did it that way, it would look something like this:

$$\frac{7}{64} \times \frac{64}{13} = \frac{448}{832} = \frac{7}{13}$$

You could get the answer much more quickly, however, if you remember that when multiplying fractions, common factors in the numerator and the denominator cancel each other out. The 64 in the numerator cancels with the 64 in the denominator, and the only factors left are the 7 in the numerator and the 13 in the denominator. In this way, you reach the final answer in one less step:

$$\frac{7}{\cancel{64}} \times \frac{\cancel{64}}{13} = \frac{7}{13}$$

Another skill in multiplying fractions you will need is illustrated in this next equation:

$$\frac{7}{13} \times \frac{3}{3} = \frac{21}{39}$$

Notice what happens when the original fraction is multiplied by a value equal to 1. The answer is equal to the original fraction, but it looks different. Multiplying a fraction by a value of 1 does not change the value of the fraction.

We will use these fraction concepts in converting between units. Suppose we measure the length of a pencil to be 15.1 centimeters, but the person who wants to know the length of the pencil would like us to tell him the answer in meters. How would we convert between centimeters and meters? First, we would need to know the relationship between centimeters and meters. According to table 1.2, *centi-* means 0.01. So 1 centimeter is the same thing as 0.01 meters. In mathematical form, we would say:

1 centimeter = 0.01 meter

Look what happens when we divide both sides by 1 centimeter:

$$\frac{\text{1 centimeter}}{\text{1 centimeter}} = \frac{\text{0.01 meter}}{\text{1 centimeter}}$$

The fraction on the right equals 1! Do you see how that works? If 1 centimeter equals 0.01 meters, then the numerator and the denominator on the right side are saying the same thing, which is why that fraction equals 1. So if we use this fraction and multiply it by a measurement, then we will not change the value of the measurement. We call this fraction a conversion factor.

Now that we know how centimeters and meters relate to one another, we can convert from one to another. First, we write down the measurement that we know:

15.1 centimeters

We then realize that any number can be expressed as a fraction by putting it over the number 1. So we can rewrite our measurement as:

$$\frac{\text{15.1 centimeters}}{1}$$

Now we can convert that measurement into meters by multiplying it with the conversion factor we determined above. We have to do it the right way so that the original measurement unit cancels out when multiplied by the conversion factor. Here's how we do it:

$$\frac{15.1\ \cancel{\text{centimeters}}}{1} \times \frac{\text{0.01 meter}}{1\ \cancel{\text{centimeter}}} = \text{.151 meter}$$

Given Unit — Conversion Factor — Wanted Unit

So 15.1 centimeters is the same as 0.151 meters. This conversion method, called the **factor-label method**, works for 2 reasons. First, since 0.01 meters is the same as 1 centimeter, multiplying our measurement by 0.01 meters over 1 centimeter is the same as multiplying by 1. Since nothing changes when we multiply by 1, we haven't altered the value of our measurement at all. Second, by putting the 1 centimeter in the denominator of the second fraction, we allow the centimeters unit to cancel (just like the 64 canceled in the previous discussion). Once the centimeters unit has canceled, the only thing left is meters, so we know that our measurement is now in meters.

This is how we will do all of our factor-label setups. We will first write the measurement we are given in fraction form by putting it over 1. We will then put the unit we do not want in the denominator of the conversion factor and put the unit we do want in the numerator. Finally, the numerical meaning of any prefixes needs to go on the opposite side of the conversion factor to get the fraction to equal 1. We will see many examples of this method, so don't be concerned if you are a little confused right now.

Here is a list of steps for the factor-label method.

1. Create a fraction out of the given measurement by placing it over 1.
2. Place the original measurement unit in the denominator of the conversion factor.
3. Place the wanted unit in the numerator of the conversion factor.
4. Place the numerical meaning of any prefixes on the opposite side of the conversion factor.
5. Multiply the given measurement fraction by the conversion factor.

It may seem odd that words can be treated exactly the same as numbers, but measuring units have just that property. Whenever a measurement is used in any mathematical equation, the units for that measurement must be included in the equation. Those units are then treated the same way numbers are treated. We will come back to this point in an upcoming section of this module.

We will be using the factor-label method for many other types of problems throughout this course, so it is very, very important for you to learn it. Also, since we will be using it so often, we should start abbreviating things so that they will be easier to write down. We will use the abbreviations for the base units listed in table 1.1, along with the prefix abbreviations listed in table 1.2. For example, kilograms will be abbreviated as kg, while milliliters will be abbreviated as mL.

Since the factor-label method is so important in our studies of chemistry, let's see how it works in example 1.1.

EXAMPLE 1.1

A student measures the mass of a rock to be 14,351 grams. What is the rock's mass in kilograms?

First, we use the definition of *kilo-* to determine the relationship between grams and kilograms:

$$1 \text{ kg} = 1{,}000 \text{ g}$$

Then we put our given measurement in fraction form:

$$\frac{14{,}351 \text{ g}}{1}$$

Then we multiply our measurement by a fraction that contains the relationship noted above, making sure to put the 1,000 g in the denominator so that the unit of grams will cancel out:

$$\frac{14{,}351 \cancel{\text{g}}}{1} \times \frac{1 \text{ kg}}{1{,}000 \cancel{\text{g}}} = 14.351 \text{ kg}$$

Given Unit   Conversion Factor   Wanted Unit

So, 14,351 grams is the same as **14.351 kilograms**.

Because we will use it over and over again, you must master this powerful technique. Also, you will see toward the end of this module that the factor-label method can become extremely complex; therefore, it is very important that you take the time now to answer "On Your Own" questions 1.1–1.3. Once you have solved the problems on your own, check your answers using the solutions provided at the end of the module.

ON YOUR OWN

1.1 A student measures the mass of a bag of sand to be 9,321 g. What is the bag's mass in kg?

1.2 If a glass contains 0.465 L of water, what is the volume of water in mL?

1.3 On a professional basketball court, the distance from the 3-point line to the basket is 724.0 cm. What is this distance in meters?

CONVERTING BETWEEN UNIT SYSTEMS

As you may have guessed, the factor-label method can also be used to convert *between systems* of units as well as within systems of units. If a measurement is done in the English system, the factor-label method can be used to convert that measurement to the metric system, or vice versa. To be able to do this, we must learn the relationships between metric and English units, as shown in table 1.3. Although these relationships are important, we will not use them very often, so you don't need to memorize them.

TABLE 1.3
Relationships between English and Metric Units

Measurement	English/Metric Relationship
Distance	1.00 inch = 2.54 cm
Mass	1.00 slug = 14.59 kg
Volume	1.00 gallon = 3.78 L

We can use this information to form conversion factors for the factor-label method the same way we did for the metric system conversions. Study example 1.2 to see how this works.

EXAMPLE 1.2

The length of a tabletop is measured to be 37.8 inches. What is that length in cm?

To solve this problem, we first put the given measurement in its fraction form:

$$\frac{37.8 \text{ in}}{1}$$

We then multiply this fraction by the conversion relationship so that the inches unit cancels:

$$\frac{37.8 \text{ \sout{in}}}{1} \times \frac{2.54 \text{ cm}}{1 \text{ \sout{in}}} = 96.012 \text{ cm}$$

Given Unit — Conversion Factor — Wanted Unit

So a measurement of 37.8 inches is equivalent to **96.012 cm**.

Give yourself a little more practice with the factor-label method by answering "On Your Own" questions 1.4–1.5.

ON YOUR OWN

1.4 How many kilograms are in 8.465 slugs?

1.5 If an object occupies a volume of 6.1236 liters, how many gallons does it occupy?

MORE COMPLEX UNIT CONVERSIONS AND PROBLEM SOLVING

Now that we have seen some simple applications of the factor-label method, let's look at more complex problems. For example, suppose we measure the volume of a liquid to be 4,523 centiliters but would like to convert this measurement into kiloliters. This is a more complicated problem because the relationship between cL and kL is not direct. In all of the previous examples, we knew the relationship between the unit we had and the unit to which we wanted to convert. In this problem, we need to add an extra step to convert from one to the other.

We would say there is an indirect relationship between the 2 units. We know how many cL are in a L and how many L are in a kL, so we can use these 2 relationships to do a 2-step conversion. First, we can convert centiliters into liters:

$$\frac{4{,}523 \ \cancel{\text{cL}}}{1} \times \frac{0.01 \text{ L}}{1 \ \cancel{\text{cL}}} = 45.23 \text{ L}$$

Given Unit Conversion Factor Wanted Unit

Then we can convert liters into kiloliters:

$$\frac{4{,}523 \ \cancel{\text{L}}}{1} \times \frac{1 \text{ kL}}{1{,}000 \ \cancel{\text{L}}} = 0.04523 \text{ kL}$$

Given Unit Conversion Factor Wanted Unit

We are forced to do this 2-step process because of the indirect relationship between the 2 prefix units in the metric system. However, we can always convert between 2 prefix units if we first convert to the base unit. To speed up this kind of conversion, we can combine these 2 steps into 1 line:

$$\frac{4{,}523 \ \cancel{\text{cL}}}{1} \times \frac{0.01 \cancel{\text{L}}}{1 \ \cancel{\text{cL}}} \times \frac{1 \text{ kL}}{1{,}000 \ \cancel{\text{L}}} = 0.04523 \text{ kL}$$

Given Unit Conversion Factors Wanted Unit

You will be seeing mathematical equations like this one as we move through the subject of chemistry, so it is important for you to understand what's going on. The first fraction in the equation above represents the measurement that we were given. Since there isn't a relationship between the unit we were given and the unit to which we will convert, we first convert the given unit to the base unit. This is accomplished with the second fraction in the equation. When the first fraction is multiplied by the second fraction, the cL unit cancels and is replaced by the L unit. The third fraction then cancels the L unit and replaces it with the kL unit, which is the unit we want. This gives us our final answer.

We solved all of the previous problems using the same steps.

1. The problem gave a measurement with a unit and asked for a different unit.
2. We planned and laid out conversion factors. Think of the sequence of unit conversions you will need to get from the initial unit to the final unit for the answer. For each change of unit in your plan, you will need a conversion factor.
3. Finally, we set up the factor-label method using the steps we learned earlier.

Try to use the above approach in example 1.3.

EXAMPLE 1.3

The mass of an object is measured to be 0.030 kg. What is the object's mass in mg?

Given Unit: kg
Wanted Unit: mg

Plan Conversion Factors: Because the relationship between milligrams and kilograms is indirect, we will plan a 2-step conversion. First, we know that:

$$1 \text{ kg} = 1{,}000 \text{ g}$$

We also know that:

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

So we need to multiply our original measurement in fraction form with both of these relationships. We must do it in such a way as to cancel out the kg and replace it with g, and then cancel out the g and replace it with mg.

Set Up Problem:

$$\frac{.030 \cancel{\text{kg}}}{1} \times \frac{1{,}000 \cancel{\text{g}}}{1 \cancel{\text{kg}}} \times \frac{1 \text{ mg}}{0.001 \cancel{\text{g}}} = 30{,}000 \text{ mg}$$

Given Unit   Conversion Factors   Wanted Unit

The object's mass is 0.030 kg, which is the same as **30,000 mg**.

ON YOUR OWN

1.6 A balloon is blown up so that its volume is 1,500 mL. What is its volume in kL?

1.7 If the length of a race car track is 2.0 km, what is it in cm?

1.8 How many mg are in 0.01 Mg?

The factor-label method is one of the most important tools you can learn for the study of chemistry (and physics, for that matter). Therefore, you must become a veritable expert at it. Try your hand at "On Your Own" questions 1.6–1.8 so that you can get some more practice.

DERIVED UNITS

We mentioned previously that units can be used in mathematical expressions in the same way that numbers can be used. Just as there are rules for adding, subtracting, multiplying, and dividing numbers, there are also rules governing those operations when using units. You will have to become very adept at using units in mathematical expressions, so let's discuss those rules now.

Adding and Subtracting Units: When adding and subtracting units, the most important thing to remember is that the units we are adding or subtracting must be identical. For example, we cannot add grams and liters. The result would not make sense physically. Since gram is a unit of mass and liter is a unit of volume, there is no way we can add or subtract them. We also cannot add or subtract kilograms and grams. Even though both units measure mass, we cannot add or subtract them unless the units are *identical*. If we did want to add or subtract them, we would have to convert the kilograms into grams or convert the grams into kilograms. It doesn't matter which way we go, as long as the units we add or subtract are identical.

Once we have identical units, we can add and subtract them using the rules of algebra. Since 2x + 3x = 5x, we know that 2 cm + 3 cm = 5 cm. In the same way, 3.1 g – 2.7 g = 0.4 g. When adding or subtracting units, we add or subtract the numbers they are associated with and then simply carry the unit along into the answer.

Multiplying and Dividing Units: When multiplying and dividing units, it doesn't matter whether or not the units are identical. Unlike addition and subtraction, we can multiply or divide any unit by any other unit. In algebra:

$$3x \text{ x } 4y = 12xy$$

When multiplying units:

$$3 \text{ kg x } 4 \text{ mL} = 12 \text{ kg x mL}$$

Similarly, in algebra:

$$6x \div 2y = 3\,\frac{x}{y}$$

When dividing units:

$$6 \text{ g} \div 2 \text{ mL} = 3\,\frac{\text{g}}{\text{mL}}$$

So when multiplying or dividing units, you multiply or divide the numbers and then do exactly the same thing to the units.

Let's use the rules we've just learned to explore a few other things about units. First, let's see what happens when we multiply measurements that have the same units. Suppose we wanted to measure the surface area of a rectangular table. From geometry, we know that the area of a rectangle is the length times the width. So, let's suppose we measure the length of a table to be 1.1 meters and the width to be 2.0 meters. Its area would be:

$$1.1 \text{ x } 2.0 = 2.2$$

What would the units be? In algebra, we would say that:

$$1.1x \times 2.0x = 2.2x^2$$

Therefore:

$$1.1 \text{ m} \times 2.0 \text{ m} = 2.2 \text{ m}^2$$

This tells us that m^2 (square meter) is a unit for area.

Let's take this one step further. Suppose we measure the length, width, and height of a small box to be 1.2 cm, 3.1 cm, and 1.4 cm, respectively. What would the volume of the box be? From geometry, we know that volume is length times width times height, so the volume would be:

$$1.2 \text{ cm} \times 3.1 \text{ cm} \times 1.4 \text{ cm} = 5.208 \text{ cm}^3$$

Therefore, cm^3 (usually called cubic centimeters or cc's) is a unit for volume. If you've ever listened to doctors or nurses talking about how much liquid to put in a syringe when administering a shot, they usually use cc's as the unit. When a doctor tells a nurse, "Give the patient 4 cc's of penicillin," he is telling the nurse to inject a 4-cm^3 volume of penicillin into the patient.

Wait a minute. Wasn't the metric unit for volume the liter? Yes, but another metric unit for volume is the cm^3. In addition, m^3 (cubic meters) and km^3 (cubic kilometers) are possible units for volume. This is a very important point. Often, several different units exist for the same measurement. The units you use will depend, to a large extent, on what information you are given in the first place. We'll see more about this fact later.

Units like cm^3 are called **derived units** because they are derived from math calculations with basic units that make up the metric system. Many of the units you will use in chemistry are derived units. We will discuss one very important physical quantity with derived units in an upcoming section of this module, but first you need to understand exactly how to use derived units in mathematical equations.

Let's suppose we want to take the volume that we previously determined for the box and convert it from cubic centimeters to cubic meters. You might think the conversion would look something like this:

$$\frac{5.208 \text{ cm}^3}{1} \times \frac{0.01 \text{ m}}{1 \text{ cm}}$$

This conversion might look correct, but there is a major problem with it. Remember what the factor-label method is designed to accomplish. In the end, the old units are supposed to cancel out, leaving the new units in their place. The way this conversion is set up, the old units *do not cancel!* When we multiply these 2 fractions together, the cm in the denominator does not cancel out the cm^3 in the numerator. When multiplying fractions, the numerator and denominator must be *identical* for them both to cancel. The cm in the denominator above must be replaced with cm^3.

How is this done? It's quite simple. Do you remember the math equation for volume? It is length times width times height. You have to provide a conversion factor for each unit of the length, width, and height.

$$\frac{5.208 \text{ cm}^3}{1} \times \frac{0.01 \text{ m}}{1 \text{ cm}} \times \frac{0.01 \text{ m}}{1 \text{ cm}} \times \frac{0.01 \text{ m}}{1 \text{ cm}}$$

We can shorten this setup by using an exponent:

$$\frac{5.208\ \text{cm}^3}{1} \times \left(\frac{0.01\ \text{m}}{1\ \text{cm}}\right)^3$$

Inside the parentheses, the m becomes m³, the cm becomes cm³, the 0.01 becomes 0.000001, and the 1 stays as 1:

$$\frac{5.208\ \cancel{\text{cm}^3}}{1} \times \frac{0.000001\ \text{m}^3}{1\ \cancel{\text{cm}^3}} = 0.000005208\ \text{m}^3$$

Given Unit Conversion Factor Wanted Unit

Now since both the numerator and denominator have a unit of cm^3, that unit cancels and is replaced with the m^3. So a volume of 5.208 cm^3 is equivalent to a volume of 0.000005208 m^3.

Since cubic meters, cubic centimeters, and the like are measurements of volume, you might have already guessed that there must be a relationship between these units and the other volume units we discussed earlier. In fact, 1 cm^3 is the same thing as 1 mL. This is a very important relationship and is something you will have to know before you can finish this module. Commit it to memory now:

1 cubic centimeter is the same as 1 milliliter (1 cm^3 = 1 mL).

Let's combine this fact with the mathematics we just learned and perform a very complicated unit conversion. If you can understand example 1.4 and successfully complete "On Your Own" questions 1.9–1.11, then you have mastered unit conversion. If things are still a bit shaky for you, don't worry. There are plenty of practice problems at the end of this module to help you practice your unit conversion skills.

EXAMPLE 1.4

The length, width, and height of a small box are measured to be 1.1 in, 3.2 in, and 4.6 in, respectively. What is the box's volume in liters?

Given Unit: in (length)
Wanted Unit: L (volume)

Plan Conversion Factors: First, determine volume. To solve this problem, we first use the geometric equation for the volume of a box:

$$V = l \times w \times h$$

Set Up Problem:

$$V = 1.1\ \text{in} \times 3.2\ \text{in} \times 4.6\ \text{in} = 16.192\ \text{in}^3$$

Plan Conversion Factors: Second, convert to liters. Now that we know the volume, we just have to convert from in^3 to L. This is a little more difficult than it sounds, however. Since there is no direct relationship between in^3 and L, we must go through a series of conversions to get to the desired unit. First, we can convert our unit from the English system to the metric system by using the following relationship:

$$1 \text{ in} = 2.54 \text{ cm}$$

To do this, we will have to cube the fraction we multiply by so that we have cm^3 and in^3.

Set Up Problem:

$$\frac{16.192 \text{ in}^3}{1} \times \left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right)^3 = \frac{16.192 \text{ in}^3}{1} \times \left(\frac{16.387 \text{ cm}^3}{1 \text{ in}^3}\right) = 265.338 \text{ cm}^3$$

Now that we have the metric volume unit, we can use the fact that a cm^3 is the same as a mL:

$$265.338 \text{ cm}^3 = 265.338 \text{ mL}$$

Now we can convert from mL to L:

Set Up Problem:

$$\frac{265.338 \text{ mL}}{1} \times \frac{0.001 \text{ L}}{1 \text{ mL}} = 0.265338 \text{ L}$$

The volume, then, is **0.265338 L**.

Alternative approach: First, convert inches to centimeters, then get the volume in cubic centimeters, then convert to milliliters, and finally convert to liters.

Set Up Problem:

We convert initial inch units to cm:

$$\frac{1.1 \text{ in}}{1} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 2.794 \text{ cm} \qquad \frac{3.2 \text{ in}}{1} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 8.128 \text{ cm}$$

$$\frac{4.6 \text{ in}}{1} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 11.684 \text{ cm}$$

We calculate volume in cm^3:

$$V = 2.794 \text{ cm} \times 8.128 \text{ cm} \times 11.684 \text{ cm} = 265.338 \text{ cm}^3$$

Finally, we convert cm^3 to L (remember that cm^3 is equal to mL):

$$\frac{265.338 \text{ mL}}{1} \times \frac{0.001 \text{ L}}{1 \text{ mL}} = \mathbf{0.265338 \text{ L}}$$

You will see that this is the same answer as above. We simply changed the order of how we did it.

MAKING MEASUREMENTS

Now that we've learned about measurement units, we need to spend a little time learning how to make measurements. After all, being able to manipulate units in mathematical equations isn't going to help us unless we can make measurements with those units to begin with. To learn how to make measurements properly, we have to know how to use measuring instruments. Let's start with a simple measuring instrument: the ruler.

ON YOUR OWN

1.9 Should you be impressed if someone says she can hold her breath for 0.00555 hours? You must first convert this to seconds to answer. (HINT: 1 hour = 60 minutes and 1 minute = 60 seconds.)

1.10 How many cm^3 are in 0.0091 kL?

1.11 The area of a room is 32 m^2. What is the area of the room in mm^2?

Suppose we wanted to measure the length of this purple line with an English ruler. We would make the measurement something like this:

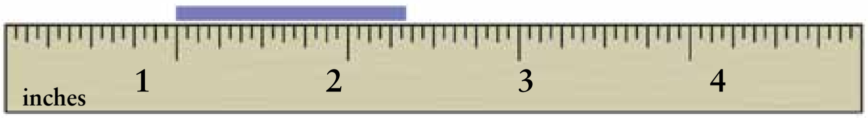


Illustration by Megan Whitaker

First, notice that we did not start the measurement at the beginning of the ruler. Instead, we lined up the ribbon with the first inch mark because it is slightly more accurate. It is very difficult to line up the edge of a ruler with the edge of the object you are measuring. This is especially true when the ruler is old and the edges are worn. So, the first rule for measuring with a ruler is to start at 1, not 0.

How would you read this measurement? First, you need to see what the scale on the ruler is. If you count the number of dashes between 1 inch and 2 inches, you will find that there are 15 of them. Every dash is worth one-sixteenth of an inch because 15 dashes break up the area between 1 inch and 2 inches into 16 equal regions.

Now that we know the scale is marked off in sixteenths of an inch, we can see that the ribbon is a little bigger than 1 5/16 of an inch. Is that the best we can do? Of course not! Because the edge of the ribbon falls between 5/16 (10/32) and 6/16 (12/32) of an inch, we can estimate that it is approximately 11/32. The proper length of the ribbon is 1 11/32 inches. Generally, chemists do not like fractions in their final measurements, so we will convert 11/32 into its decimal form to get a measurement of 1.34375 inches. Later on we will see that this measurement has far too many digits in it, but for now we will assume that it is okay.

Let's measure that same ribbon with a metric ruler:

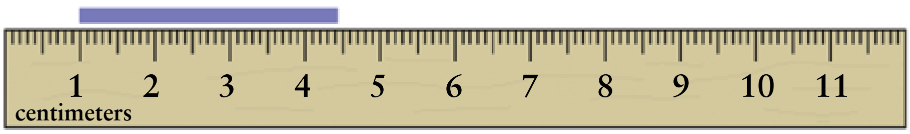


Illustration by Megan Whitaker

Now what measurement do we get? There are 9 small dashes between each cm mark; therefore, the scale of this ruler is one-tenth of a cm, or 0.1 cm. This is typical of metric rulers. They are almost always marked off in tenths since all the prefixes in the metric system are multiples of 10. If you think about it, 1 mm = 0.1 cm, so you could also say that each small dash is 1 mm. The ribbon is between 3.4 cm and 3.5 cm long. (The printing of your specific page could alter your measurement slightly.) Using our method of approximating between the dashes, we would say that the ribbon is 3.41 cm long.

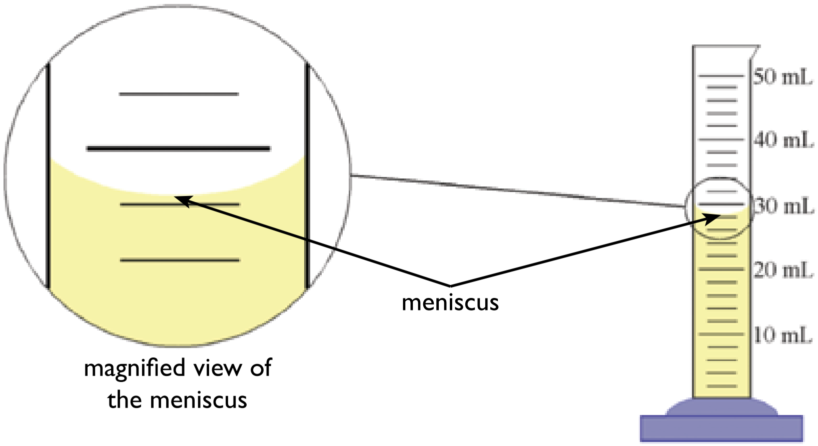
How do we deal with the part of the line between the dashes? Here is a rule you will need to follow with any scientific instrument. You will always estimate one digit beyond what the instrument is marked. We can say 3.41 cm is the length of the line. Our instrument is marked off in 0.1 cm, so we will always report the measurement to the nearest 0.01 cm. What if you measure 3.43 cm and someone else measures 3.41 cm? There is nothing wrong with this because the last digit of any measurement is an estimate.

Whenever you are using a measuring device marked with a scale, be sure to use it the way we have used the rulers here. First, determine what the dashes on the scale mean. Then, try to estimate between the dashes if the object you are measuring does not exactly line up with a dash. That gives you as accurate a measurement as possible. You should always strive to read the scale to *the next decimal place* if possible. For example, on a metric ruler, the scale is marked off in 0.1 cm, so you should read the ruler to 0.01 cm, as discussed above.

One physical quantity that chemists measure frequently is volume because they spend a great deal of time mixing liquids. When chemists measure volume, one of the most useful tools is the **graduated cylinder**. This device looks a lot like a rain gauge. It is a hollow cylinder with markings on it. These markings, called graduations, measure the volume of liquid that is poured into the cylinder.

In the last experiment you will perform in this module, you will use a graduated cylinder (or a suitable substitute) to measure volume; so you need to know how to do this. When liquid is poured into a cylinder, the liquid tends to creep up the edges of the cylinder. This is because there are attractive forces between the liquid and the cylinder. Therefore, liquid poured into a graduated cylinder does not have a flat surface. Instead, it looks something like figure 1.2:

FIGURE 1.2
The Meniscus
Illustration by Megan Whitaker



The curved surface of the yellow liquid is called the **meniscus** (muh nis' kus). To determine the volume of the liquid in any graduated cylinder, you must read the level of the liquid from the bottom of the meniscus. On the graduated cylinder in figure 1.2, there are 4 dashes between each marking of 10 mL, splitting the distance between the 10 mL marks into 5 divisions. This means that each dash must be worth 2 mL. If you look at the bottom of the meniscus in the figure, you will see that it is between 28 and 30 mL. Is the volume 29 mL then? No, not quite.

In the 2 examples we considered before, it was hard to guess how far between the dashes the object's edge was because the dashes were very close together. In this example, the dashes are farther apart, so we can be a bit more precise in our final answer. For the volume to be 29 mL, the bottom of the meniscus would have to be exactly halfway between 28 and 30. Clearly, the meniscus is much closer to 28 than to 30. So the volume is really between 28 and 29, and probably a little closer to 28. We would estimate that the proper reading is 28.3 mL. It could be as low as 28.1 or as high as 28.5, so 28.3 is a good compromise. Remember, you need to try to read the scale to the next decimal place. Since the scale is marked off in increments of 2 mL, you must try to read the answer to 0.1 mL. Experiment 1.3 will give you some practice at this kind of estimation.

ACCURACY, PRECISION, AND SIGNIFICANT FIGURES

Now that we've learned a bit about taking measurements, we need to discuss when measurements are good and when they are not. In chemistry, there is always some uncertainty in the value of a measurement. We can describe the measurement in 2 ways—its accuracy and its precision. Even though these words are used interchangeably in daily life, there's an important distinction between them.

Accuracy—An indication of how close a measurement is to the true value.
Precision—An indication of the scale on the measuring device that was used.

In other words, the more correct a measurement is, the more accurate it is. The smaller the scale on the measuring instrument, the more precise the measurement.

So let's look again at the ribbon measurement as an example. Suppose we used a ruler with a scale marked off in 0.1 cm and measured a length of 3.45 cm. What does that number mean? It means that the length of the ribbon, as far as we could tell, was somewhere between 3.445 and 3.455 cm long. We could not determine the length of the ribbon any better than that because our ruler was not *precise* enough to do any better.

On the other hand, if we found a ruler with a scale marked in increments of 0.01 cm, we could get a more precise measurement. For example, we could get a measurement of 3.448 cm because estimating between the dashes gives us one more decimal place. Since the ruler is marked off in hundredths, we can get a measurement out to the thousandths place. That extra digit in the thousandths place nails down the length better. It would be impossible to obtain so precise a measurement from the ruler we used in the example above, so the new ruler provides a more precise measurement. These examples show that the precision of our measurements depends completely on the measuring devices we use. The smaller the scale on the instrument, the more precise our measurement will be.

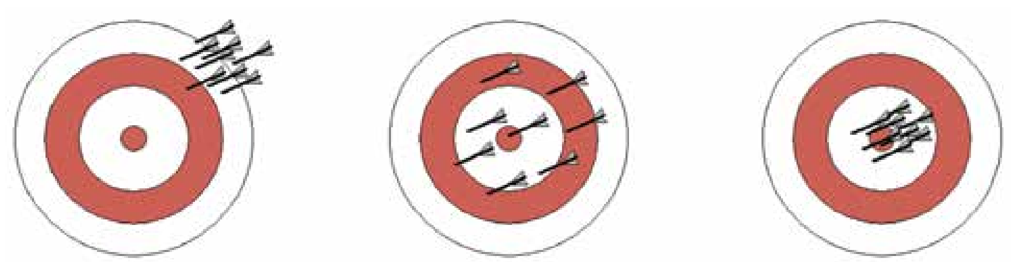
However, suppose we used the second ruler improperly. Maybe we read the scale incorrectly or didn't line up the ribbon to the ruler very well and got a measurement of 3.118 cm. Even though this measurement is more *precise* than the one we made with the first ruler, it is significantly less *accurate* because it is way off of the correct value of 3.448 cm. The *accuracy* of our measurement depends on how carefully and correctly we use the measuring device. In other words, a measurement's *precision* depends upon the instrument, whereas a measurement's *accuracy* depends upon the person doing the measurement.

Since a measurement's precision depends on the instrument used, the only way to improve precision is to get a better, more precise instrument. However, there are other ways to improve accuracy. First, make sure you understand the proper methods of using each instrument. Second, practice making measurements, which will help your skill and your accuracy.

The most practical way to improve your accuracy in measurement is to make your measurement several times and average the results. This averages out all the little differences that can occur between measurements, even while using the same instrument. An even better way of assuring accuracy is to have several *different* people make the measurements and average all their answers together. The more individual measurements are made, the more accurate the average of them will be.

Let's illustrate this whole idea of accuracy and precision in another way. Suppose you were throwing darts at a dart board. Figure 1.3 shows 3 possible outcomes that we will discuss.

FIGURE 1.3
Accuracy and Precision
Illustration by Megan Whitaker



Precise, but not accurate — Accurate, but not precise — Both accurate and precise

The first target on the left has all the darts clumped together, but they are way off the bull's-eye. If we made several measurements with a precise device but used it wrongly every time or the device had a flaw, it would give us numerous measurements that were very close to one another but far from the true value. This example shows a lot of precision, but not much accuracy.

The middle target has the darts surrounding the bull's-eye, but they are far from one another. If we used a measuring device that is not very precise but used it correctly, it would give us similar results. This may be because we had a hard time estimating between the marks on the scale of the instrument. This example shows accuracy, but not much precision.

The last target on the right has all darts clumped together, and they are on the bull's-eye. This is an example of measurements that are both accurate and precise. They are accurate because they average out to the correct value of the bull's-eye, and they are precise because they are very close to one another, indicating that a precise measuring device was used. This example is what every chemist desires when making measurements.

Since accuracy and precision are very important, we need to know how to evaluate the accuracy and precision of our measurements. The way to determine the accuracy of a measurement is to compare it to the correct value. If you have no idea what the correct value is, determining your measurement's accuracy is difficult. It is not impossible, but we will not spend time in this course on this topic.

Determining the precision of a measurement is quite easy. To determine the precision of a measurement and an instrument, you merely need to look at its significant figures. But what is a significant figure? It is a digit that is read from an instrument. That purple line was 3.41 cm long. All of those digits came from the ruler, so that measurement has 3 significant figures. The volume of liquid in the graduated cylinder was 28.3 mL. Again, all of those digits came from the instrument, so they are significant figures. A significant figure is a measured digit!

If 2 instruments measure the same thing, the one which gives a significant figure in the smallest decimal place is the more precise instrument. For example, 2.545 cm is more precise than 2.54 cm because 2.545 cm has more significant figures. There are 4 rules you need to remember to determine the number of significant figures:

1. All nonzero digits are significant.
2. All zeros in front of the first 1–9 digit are not significant.
3. All zeros between 2 significant figures are significant.
4. All zeros at the end of a number *and* to the right of the decimal point are significant.

TABLE 1.4
Examples of Significant Figure Rules

Number	Example	Number of Significant Figures
Nonzero digits	9,341	4
Zeros in front of first 1–9 digit	0.000564	3
Zero between 2 significant figures	120.043	6
Zero at end of number *and* to right of decimal point	510.0 510	4 2

Counting significant figures is very important in science and in our ability to understand measurements, so you must have a firm grasp on this concept. Read through example 1.5 and follow the logic. After that, try "On Your Own" question 1.12.

EXAMPLE 1.5

Count the significant figures in each of the following numbers:

a. 3.234 b. 6.016 c. 105.340 d. 0.00450010 e. 2,330

(a) Since every digit is nonzero, every digit is a significant figure (first rule). This means there are **4 significant figures** in this number.

(b) Three of the digits are nonzeros and therefore are significant figures (first rule). The 0 is also significant because it is between 2 significant figures (second rule). So there are **4 significant figures** in the number.

(c) Four of the digits are nonzeros and therefore are significant figures (first rule). The 0 between the 1 and 5 is significant because it's between 2 significant figures (second rule). The last 0 is also significant because it is at the end of the number and to the right of the decimal point (third rule). The answer is there are **6 significant figures** in the number.

(d) The 3 nonzero digits are all significant figures, as are the zeros between the 5 and 1. The 0 at the end is also a significant figure. However, the first 3 zeros are not significant because they are not between 2 significant figures and they are not at the end of the number to the right of the decimal. They are important, but they are not measured. There are **6 significant figures** in the number.

(e) The 3 nonzero digits are significant figures. The zero is not significant because it is before, not at the end of, the number to the right of the decimal. There are **3 significant figures** in the number.

ON YOUR OWN

1.12 How many significant figures are in the following measurements?

a. 3.0220 cm
b. 0.0060 m
c. 1.00450 L
d. 61.054 kg
e. 300,000 mm

As we have seen, the precision of our instrument determines the number of significant figures we can report in a measurement. In our graduated cylinder example, we decided that we could reasonably approximate our measurement to somewhere between 28 and 29 mL. If we can do that, then we can report our answer to the nearest tenth of a mL, giving us a 3-significant-figure answer of 28.3 mL. If, instead, our graduated cylinder had been marked off in tenths of a mL, we could probably approximate the measurement to somewhere between 28.2 and 28.3 mL, allowing us to have a 4-significant-figure answer like 28.26 mL.

In the example which used an English ruler, we said that our final answer, 1.34375 inches, had too many digits in it. Now hopefully you can see why. According to this number, our ruler was precise enough to measure distance of one-hundred-thousandth of an inch! That's far too much precision. Most English rulers are, at best, precise to 0.01 inches. Therefore, the proper length of the ribbon that you should report is 1.34 in.

Suppose we had another ribbon to measure:

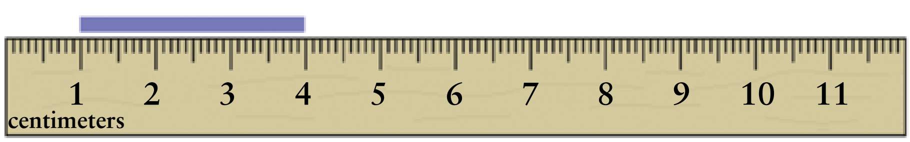


Illustration by Megan Whitaker

How would we report its measurement? Would we say that this ribbon is 3 cm long? Actually, that measurement is not quite right. The ribbon does seem to end right on the 4 cm line, so there is no need to do any approximations here. Why, then, is 3 cm a wrong answer for the length of the ribbon?

The problem with reporting the length of the ribbon as 3 cm is that we are not being as precise as we can be. Since the ruler's scale is marked off in 0.1 cm, we can safely report our answers to the hundredths of a cm. If the ribbon's edge had fallen between 2 dashes, we could have approximated as we did above. Therefore, the precision of the ruler is to the hundredths place. Therefore, if the object's edge falls right on one of the dashes, do not throw away precision. Report this length as 3.00 cm. This tells someone who reads the measurement that the ribbon's length was measured to a precision in the hundredths of a cm.

If you report the length as 3 cm, that means the ribbon could be as short as 2.5 cm or as long as 3.4 cm. Both of those measurements round to 3. But the ruler we used was much more precise. It determined the length of the ribbon to be 3.00 cm. So the ribbon is somewhere between 2.995 and 3.004 cm long. Keeping all of the significant figures that you can is a very important part of doing chemistry experiments. You will get some practice at this in experiment 1.3.

Reporting the precision of a measurement is just as important as reporting the number itself. Why? Let's suppose that the No-Weight Cookie Co. just produced a diet cookie that they claim has only 5 calories per cookie. To confirm this claim, researchers did several careful experiments and found that, in fact, there were 5.4 calories per cookie. Does this result mean that the No-Weight Cookie Co. lied about the number of calories in its cookies? No. When the company reported that there are 5 calories per cookie, the precision of their claim indicated that there could be anywhere from 4.5 to 5.4 calories per cookie. The researchers' finding was more precise than the company's claim; nevertheless, the company's claim was accurate.

SCIENTIFIC NOTATION

Since reporting the precision of a measurement is so important, we need a notation system that allows us to do this no matter what number is involved. As numbers get very large, it becomes more difficult to report their precision properly. For example, suppose we measured the distance between 2 cities as 100.0 km. According to our rules of precision, reporting 100.0 km as the distance means that our measuring device was marked off in units of 1 km, and we estimated between the marks to come up with 100.0 km. However, suppose our measurement wasn't that precise. Suppose the instrument we used could determine the distance only to within 10 km? How could we write down a distance of 100 km and indicate that the precision was only to within 10 km?

The answer to this question lies in the technique of **scientific notation**. In scientific notation, we write numbers so that no matter how large or how small they are, they always include a decimal point. Remember, a number can be represented in many different ways. The number 4, for example, could be written as 2 × 2 or 4 × 1 or simply 4. Each one of these is an appropriate representation of the number 4. In scientific notation, we always represent a number as a something times a power of 10. For example, 50 could be written in scientific notation as 5 × 10. The number 150 could be written as 1.5 × 100 or 15 × 10.

Do you see why this helps us in writing down the precision of our original measurement? Instead of writing the distance as 100 km, we could write it as 1 x 100 or 1.0 x 100 or 1.00 x 100. How does this help? According to our rules of significant figures, the 0 in 1.0 is significant because it is at the end of the number and to the right of the decimal. By writing down our measurement as 1.0 x 100, we indicate that the 0 was measured and that the measurement is precise to within 10 km. There is no way to do that with normal decimal notation because neither of the zeros in 100 is significant. Scientific notation, then, gives us a way to *make* zeros significant if they need to be. If our measurement of 100 km was precise to within 1 km, we could indicate that by reporting the measurement as 1.00 x 100 km. Since both zeros in 1.00 are significant, this tells us that both zeros were measured, so our precision is within 1 km.

Since numbers that we deal with in chemistry can be very big or very small, we use one piece of mathematical shorthand in scientific notation. Recall from algebra that 100 is the same as 10^2. We will use this shorthand to make the numbers easier to write down. Scientific notation always has a number with a decimal point right after the first digit times a 10 raised to some power.

One other advantage of using scientific notation is that it simplifies the job of recording very large or very small numbers, making mistakes in computations less likely. For example, there are roughly 20,000,000,000,000,000,000,000 particles in each breath of air that we take. Numbers like that are very common in chemistry. In scientific notation, the number would be 2×10^{22}. That's much easier to write down!

How did do we know to raise the 10 to the 22nd power? To get the decimal point right after the 2, we would have to move it to the left 22 digits, which is equivalent to multiplying by 10^{22}. When putting a large number into scientific notation, all we need to do is count the number of spaces the decimal point needs to move and then raise the 10 to that power.

$$20{,}000{,}000{,}000{,}000{,}000{,}000{,}000.0 = 2 \times 10^{22}$$

Chemistry also deals with very small numbers. For example, one of the things we will discuss in great detail in several upcoming modules is a particle called a proton. The proton has a mass of about 0.00000000000000000000000000167 kg. This number is very cumbersome to write down, so we will use scientific notation to make our job a little easier. In scientific notation, the proton's mass is 1.67×10^{-27} kg. Why raise the 10 to the –27th power? When numbers are raised to the negative power, they are smaller than 1. So when we multiply a number by 10 raised to a negative power, we shift the decimal place the other way. To get the decimal point to be right after the 1, we have to move it 27 places. Since we moved it to the right 27 places, we multiply it by 10^{-27}.

$$0.00000000000000000000000000167 = 1.67 \times 10^{-27}$$

You will need to follow 2 basic rules for scientific notation in this course.

1. Place only 1 digit (not a 0) in front of the decimal point.
2. Only significant figures go in front of the multiplication sign.

See how this works by following example 1.6, and then make sure you understand this technique by completing "On Your Own" questions 1.13–1.14.

EXAMPLE 1.6

Convert the following numbers into scientific notation:

a. 20,300 b. 3,151,367 c. 234,000 d. 0.000002340 e. 0.000875

(a) The decimal place must be moved to the left by 4 digits to get it next to the 2. Since we are dealing with a big number, we have to multiply by a 10 raised to a positive power. Therefore, the answer is **2.03×10^4**. Since the last 2 zeros to the right of the 3 are *not* significant as the number is written, we must drop them in our answer. All zeros are significant in 2.0300×10^4.

(b) The decimal place must be moved to the left 6 places and the number is big, so the answer is **3.151367×10^6**.

(c) The decimal place must be moved to the left 5 places, and since it is a big number, the answer is **2.34×10^5**. The last 3 zeros were dropped because as written, they are not significant.

(d) The decimal must be moved 6 places to the right. Since this is a small number, we are dealing with a negative exponent, so the answer is **2.340×10^{-6}**. In this case, the final 0 cannot be dropped because, based on our rules of significant figures, a 0 at the end of a number and to the right of the decimal point is significant.

(e) The decimal point must be moved 4 places to the right. Since it is a small number, the answer is **8.75×10^{-4}.**

Convert the following numbers from scientific notation back into decimal form.

(a) 3.45×10^{-5} (b) 2.3410×10^7 (c) 1.89×10^{-9} (d) 3.0×10

(a) Since the 10 is raised to a negative power, the decimal point must be moved to make it small. The power of –5 tells us that we move it 5 spaces, so the answer is **0.0000345**.

(b Since the power of 10 is positive, we must move the decimal point to make the number bigger. The power of 7 tells us we must move it 7 places, so the answer is **23,410,000**. Note that we cannot indicate that the 0 after the 1 is significant in this notation. It is clearly significant in the original number, so it is impossible to properly represent the precision of this number in decimal form.

(c) We must move the decimal point 9 places and make the number smaller, so the answer is **0.00000000189**.

(d) Since the exponent is not listed, we assume it's 1. That means that we move the decimal point 1 place so that the number gets bigger, so the answer is **30**. Once again, there is no way to indicate that the 0 is significant, as it is in the original number.

ON YOUR OWN

1.13 Convert the following numbers from decimal form to scientific notation.

a. 26,089,000
b. 12,000,000,003
c. 0.00009870
d. 0.980

1.14 Convert the following numbers from scientific notation to decimal form.

a. 3.456×10^{14}
b. 1.2341×10^{3}
c. 3.45×10^{-5}
d. 3.10×10^{-1}

USING SIGNIFICANT FIGURES IN MATHEMATICAL PROBLEMS

Now that we have the ability to write down any measurement with its proper precision, there is only one more topic on significant figures that we need to discuss. We need to know how to use our concepts of significant figures when we work mathematical problems. Suppose we had 2 measurements and wanted to add them together. Since each measurement has its own precision, the final answer would also have a certain precision. How do we know the precision of our answer?

For example, suppose we measured the total length of a knife to be 25.46 cm. Later, someone else measured the length of the knife handle with a less precise ruler and got 7.8 cm. If we wanted to determine the length of the knife's blade, either we could measure it, or we could say that the blade's length was the total length of the knife minus the length of the handle, or 25.46 cm – 7.8 cm. If we do the subtraction, we get 17.66 cm. This answer is too precise because the knife handle was measured with a less precise ruler. The answer is limited to the least precise instrument, so the proper answer is 17.7 cm.

To add, subtract, multiply, or divide measurements, we will use 2 rules about using significant figures in mathematical equations. You will be using these rules over and over again throughout this course, so you will be expected to know them:

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

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

Example 1.7 shows how these rules work.

EXAMPLE 1.7

A student measures the mass of a jar that is filled with sand and finds it to be 546.2075 kg. A note on the jar says, "When empty, this jar has a mass of 87.61 kg." What is the mass of the sand in the jar?

Since 546.2075 kg is the mass of both the jar and the sand, and since 87.61 kg is the mass of the jar alone, the mass of the sand must be the difference between the 2:

$$\begin{array}{r} 546.2075 \text{ kg} \\ - \ 87.61 \quad \text{kg} \\ \hline 458.5975 \text{ kg} \end{array}$$

However, since the precision of the jar's mass only goes out to the hundredths place, that's the best we can do in our final answer. Therefore, the mass of the sand is **458.60 kg**. Note that this number has more significant figures than 87.61. That doesn't matter because in addition and subtraction, we do not count significant figures; we look only at precision.

A woman runs 3.012 miles in 0.430 hours. What is her average speed?

We can find her average speed by dividing the distance traveled by the time:

$$\text{Speed} = 3.012 \text{ miles} \div 0.430 \text{ hour} = 7.004651163$$

The 3.012 miles has 4 significant figures, while 0.430 hours has 3. Therefore, our final answer must have 3 significant figures, making it **7.00 miles/hour**

Now that we have learned these rules, you will be expected to use them *in all further mathematical operations!* Whether you are working an "On Your Own" problem, a practice problem, a test problem, or an experiment, you will use these rules. In the examples and answers for all previous problems, these rules have not been followed, but they will be from now on. By the time you finish the next couple of modules, keeping track of significant figures and precision should be second nature to you.

There is one more point that you must understand about significant figures before you get some practice using the rules. When making unit conversions, you might be tempted to round everything to 1 significant figure because of the conversion relationships. For example, when you convert 121 g into kg, you use the following equation:

$$\frac{121 \cancel{\text{g}}}{1} \times \frac{1 \text{ kg}}{1{,}000 \cancel{\text{g}}}$$

Note that the 1 kg, the 1 in the denominator of the first fraction, and 1,000 g all look like they have only 1 significant figure. You might be tempted to round your answer to 1 significant figure. However, that would not be correct. The reason is simple: These 3 numbers all come from definitions. They are infinitely precise. The 1 kg is really 1.000... kg, and the 1,000 g is really 1,000.000... g because *exactly* 1 kilogram is defined to be *exactly* 1,000 g. In the same way, the 1 on the bottom of the first fraction is really 1.000... because it is an integer. The *only* number in this equation that has a limited number of significant figures is the 121 g (it is a measurement), so the answer is 0.121 kg.

In general, then, the prefixes used in the metric system as well as the integers used in fractions are infinitely precise and have an infinite number of significant figures. As a result, we ignore them when determining the significant figures in a problem. This is a very important rule:

The definitions of the prefixes in the metric system and the integers used in fractions are not considered when determining the significant figures in the answer.

Get some practice making measurements, using them in mathematical equations, and keeping track of significant figures by performing experiment 1.3.

EXPERIMENT 1.3

PURPOSE: To compare conversions to measurements.

MATERIALS:

- Book (not oversized)
- Metric and English rulers
- Safety goggles

QUESTION: How do measurements compare to conversions?

HYPOTHESIS: Write a hypothesis about how close you expect your conversions to be to measurements.

PROCEDURE:

1. Lay the book on a table and measure its length in inches. Read the ruler as shown in the measurement section above, estimating any answer that falls between the markings on the scale. Next, convert the fraction to a decimal (as we did in the measurement section above) and round it to the hundredths place because that's the precision of an English ruler.
2. Measure the width of the book in the same way.
3. Now that you have the length and width measured, multiply them together to get the surface area of the book. Since you are multiplying inches by inches, your area unit should be in^2. Remember to count the significant figures in each of the measurements and round your final answer so that it has the same number of significant figures as the measurement with the least number of significant figures.
4. Use the relationship given in table 1.3 to convert the length measurement into cm. Do the same thing to the width measurement, making sure to keep the proper number of significant figures. Note that the relationship between inches and centimeters is exact. The 2.54 cm should not be taken into account when considering the significant figures because 1 inch is exactly 2.54 cm.
5. Use the metric ruler to measure the length and width of the book in centimeters. Once again, do it as shown in the measurements section above. If the scale of the ruler is marked off in 0.1 cm, then your length and width measurements should be written to the hundredths of a centimeter. Compare these answers to the length and width you calculated by converting from inches. They should be nearly the same. If they are different by only a small percentage, there is no problem. However, if they differ by more than a small percentage, recheck your measurements and your conversions.
6. Multiply the length and width measurements you took with the metric ruler to calculate the surface area of the book in cm^2. Use the relationship between inches and centimeters to convert your answer into in^2. Remember, since you are using a derived unit, the conversion is more complicated. You might want to review example 1.4.

7. Now compare the converted value for the surface area to the one you calculated in step 3 using your English measurements. Once again, they should be equal or close to equal. If not, you have either measured wrongly or made a mistake in your conversion.
8. Clean up and return everything to the proper place.

CONCLUSION: Write something about how well you made your measurements.

MEASURING TEMPERATURE

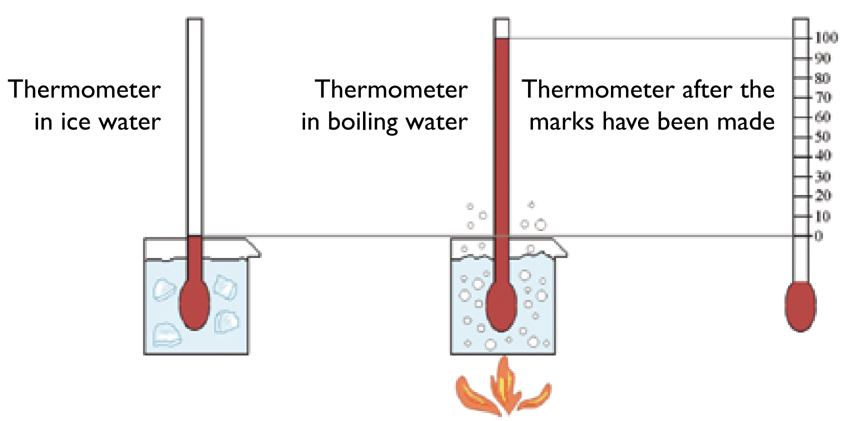
In chemistry, we will be measuring and making calculations with temperature, so we need to know what units are used in the measurement. The temperature unit that you are probably most familiar with is **Fahrenheit** (abbreviated as °F). We hear this unit used often by weather reporters talking about tomorrow's weather and how warm or cold it will be. Although this is a very common temperature unit, it is not used by chemists. Instead, chemists use one of 2 other temperature units: **Celsius** (sel' see us; abbreviated °C) or **Kelvin** (kel' vuhn; abbreviated K). First we need to see how these units are defined, and then we will see how they relate to Fahrenheit and why chemists use them.

When we measure temperature, we are measuring how much the liquid within the thermometer is expanding. Therefore, we must find a way to relate that measurement to a unit which means temperature. We do this in the following way:

1. Immerse a thermometer in a mixture of ice and water.
2. Make a mark where we see the liquid in the thermometer and assign a value to that mark. In the Celsius temperature scale, we call it exactly 0°C. In the Fahrenheit scale, we give that mark a value of exactly 32°F.
3. Immerse the thermometer in a pot of boiling water.
4. Make a mark where we see the liquid in the thermometer and assign it a value of exactly 100°Celsius or exactly 212°Fahrenheit.
5. Divide the distance between the 2 marks into equal divisions. Then we have a temperature scale.

This method for defining a temperature scale is illustrated in figure 1.4.

FIGURE 1.4
Making a Celsius Thermometer
Illustration by Megan Whitaker



This process of using certain physical measurements to define the scale of a measuring device is called calibration. This particular calibration makes use of a surprising fact in chemistry:

If ice and water are thoroughly mixed, the temperature of the mixture will stay the same (0.0°C or 32.0°F), regardless of the amount of ice or water present.

This might sound rather surprising, but it is true. Even though you might think that a little water with a lot of ice is colder than a lot of water with a little ice, they are actually the same temperature! Equally surprising is this fact:

Boiling water is always at the same temperature (100.0°C or 212.0°F at standard atmospheric pressure) whether it is boiling rapidly or hardly boiling at all.

Now that we know how the Celsius temperature unit is defined, we can learn how it relates to the Fahrenheit unit. It makes sense that Fahrenheit and Celsius relate to one another since they both measure the same thing: temperature. They are related by a very simple equation:

$$°C = \frac{5}{9}(°F - 32) \qquad \text{Equation 1.1}$$

In this equation, °C represents the temperature in degrees Celsius, and °F stands for the temperature in degrees Fahrenheit. So if you must use a Fahrenheit thermometer in your experiments, you can use this equation to convert your measurements into Celsius. Please note one very important thing about this equation: The 5, 9, and 32 are all exact. Therefore, you need not consider their significant figures. They have infinite precision and an infinite number of significant figures. The only significant figures you must consider are those of the original measurement. Using this equation, we will report our answer using the multiplication rule even though there is a subtraction in the equation. Example 1.8 will help show you how this is done.

EXAMPLE 1.8

A student uses a Fahrenheit thermometer to do a chemistry experiment but then must convert his answer to Celsius. If the temperature reading was 50.0°F, what is the temperature in Celsius?

To solve this one, we simply use equation 1.1:

$$°C = \frac{5}{9}(50.0 - 32)$$

$$°C = 10.0$$

There are 3 significant figures in the original measurement. Since the other numbers in this equation are exact, the answer must have 3 significant figures. Therefore, the answer is **10.0°C**.

We usually say that room temperature is about 25°C. What is this temperature in Fahrenheit?

To solve this one, we must first rearrange equation 1.1 using algebra. Once we do this, we get the following equation:

$$°F = \frac{9}{5}(°C) + 32$$

$$°F = \frac{9}{5}(25) + 32$$

$$°F = 77$$

The presence of only 2 significant figures in the original number means only 2 significant figures in the end; therefore, the temperature is **77°F**.

Try "On Your Own" questions 1.15–1.16 to see whether or not you fully understand this type of conversion.

ON YOUR OWN

1.15 Normal body temperature is 98.6°F. What is this temperature in Celsius?

1.16 Rubbing alcohol boils at 180.5°C. What is the boiling temperature of water in Fahrenheit?

What about the other unit mentioned earlier? The Kelvin temperature unit is a special unit that we will use quite a bit in later modules. It is special because we can never reach a temperature of 0 Kelvin or lower, for reasons we will see in a later module. This fact makes the Kelvin temperature scale different from most others. After all, anything colder than ice water has a negative temperature in Celsius units. This means that temperatures less than 0 are quite common in the Celsius scale. Although not quite as common, it is possible to reach temperatures less than 0 in the Fahrenheit scale as well. It is impossible for anything in nature to reach 0 Kelvin or below. Since we can never get to or go below 0 Kelvin, the Kelvin temperature scale is often called an **absolute temperature scale**.

Once we have a temperature in units of degrees Celsius, converting it to Kelvin is simple. All we do is add 273.15 to the measurement. In mathematical terms, we would use this equation:

$$K = °C + 273.15 \qquad \text{Equation 1.2}$$

K is the temperature in units of Kelvin, and °C is the temperature in units of Celsius. In this equation, the 273.15 is *not* exact. Its precision plays a role. Note that since this equation involves adding, we use the rules of addition and subtraction when determining the significant figures involved. Those rules are *different* from the ones for multiplication and division, so be aware of that. Example 1.9 will show you how to use this equation.

EXAMPLE 1.9

What is the boiling temperature of water in Kelvin?

This conversion is a snap. We just realize that water boils at 100.0°C. If we put that temperature into equation 1.2, we get this:

$$K = 100.0 + 273.15 = 373.15$$

The original temperature goes out to the tenths place, while 273.15 goes out to the hundredths place. The rules for significant figures in adding tell us that the answer must have the same precision as the least precise number in the equation. Therefore, our final answer is **373.2 K**.

The lowest temperature that has ever been recorded in the United States of America is -80.0°F. What is this temperature in Kelvin?

Since the only way we can get to Kelvin is by adding 273.15 to the temperature in Celsius, we must first convert °F into °C:

$$°C = \frac{5}{9}(-80.0 - 32)$$

$$°C = -62.2$$

Now that we have the answer in °C, we can easily convert to Kelvin:

$$K = -62.2 + 273.15 = 210.95$$

Our final answer is **211.0 K**. Our rules for adding tell us that the precision must be kept to the tenths place because that is the same precision as the least precise number in the equation. That's why our final answer goes out to the tenths place. So you see, even very, very cold temperatures in the Celsius and Fahrenheit temperature scales are still rather large numbers in the Kelvin temperature scale!

ON YOUR OWN

1.17 What is the Fahrenheit equivalent of 0.00 Kelvin? (Use 3 significant figures for this measurement.)

Now cement your knowledge of temperature conversions with "On Your Own" question 1.17.

THE NATURE OF A SCIENTIFIC LAW

One way to approach chemistry or any other science is to look around you and try to think of logical explanations for what you see. You would certainly observe, for instance, that different substances have different forms and appearances. For example, some substances are gases, some are liquids, and some are solids. Some are hard and shiny, but others are soft and dull. You would also observe that different substances behave differently. Iron rusts, but gold does not; copper conducts electricity, but sulfur doesn't. How can you explain these and a vast number of other observations?

God made our world far too complex for us to understand by looking and thinking alone. We need to ask specific questions and conduct experiments to find answers. Scientists develop laws through experimentation and observation. After experimenting on or observing some facet of nature, they formulate a hypothesis to explain their observations. A **hypothesis** is no more than an educated guess that attempts to explain some aspect of the world around us. For example, when early scientists observed rotting meat, they always saw maggots crawling around on it. This led them to form the hypothesis that maggots are created from rotting meat.

Once a hypothesis has been formulated, scientists test it with more rigorous experiments. For example, after forming the hypothesis that maggots are created from rotting meat, early scientists did experiments to make sure that the maggots were not coming from something else. They would put rotting meat on a shelf high in the air to make sure that no maggot could crawl up to it. Even when the rotting meat was put high in the air, maggots still appeared on it. To early scientists, such experiments confirmed their hypothesis. Although there was no way for maggots to crawl up to the rotting meat, they did indeed appear on it. Many similar experiments convinced early scientists that their original hypothesis was correct.

Once a hypothesis is confirmed by more rigorous experimentation, it is considered a **theory**. After numerous experiments, the theory may be considered a **scientific law**. A scientific law is really nothing more than an educated guess that has been confirmed over and over again by experimentation. The problem with putting too much faith in a scientific law is that the experiments that established it might be flawed, making the scientific law itself flawed.

science and creation

We study science to learn more about creation and, ultimately, the Creator. God is the one who holds it all in His hands and uses it for His glory. Early scientists who were experimenting with rotting meat and maggots called their theory the theory of spontaneous generation. As the centuries passed, many more experiments were done to test the theory. Those experiments seemed to support the idea that life, such as maggots, could be created from nonlife, such as rotting meat. All of the experiments done to confirm this theory, however, were flawed. For example, Francesco Redi, an Italian physician, showed that if the rotting meat was completely isolated from the outside world, no maggots would appear; however, microscopic organisms did. French scientist Louis Pasteur eventually performed careful experiments that overturned the theory of spontaneous generation. His work showed that even microscopic organisms could not arise from nonlife but came to the meat by dust particles that blew in the wind.

The point of this story is to illustrate that when you read about scientific results, you must keep in mind that scientific theories are not laws of nature and can never be absolutely proven. There is always a chance that a new experiment might give results that can't be explained by a present theory. All a theory can do is provide the best explanation available at the time. If new experiments uncover results that present theories can't explain, the theories will have to be modified or perhaps even replaced. Science experiments are a good way to try to understand the nature of God's creation, but they are not absolute truth. Remember that.

salt and light

Bishop Robert Grosseteste (1175–1253) was an English statesman, philosopher, theologian, and scientist. He was one of the first scientists to establish a framework for what would later become the scientific method. Besides being a great scientist, Grosseteste was a strong Christian. He taught that the purpose of inquiry was not to come up with great inventions, but instead to learn the reasons behind the facts. In other words, he wanted to explain why things happened the way they did. That's the essence of science. He said that "just as the light of the sun irradiates the organ of vision and things visible, enabling the former to see and the latter to be seen, so too the irradiation of a spiritual light brings the mind into relation with that which is intelligible" (Stevenson 1899, 52).

Stained glass window by William Morris (to the designs of Burne-Jones) [Photo: public domain]

EXPERIMENTATION AND THE SCIENTIFIC METHOD

As we go about studying chemistry, you will conduct experiments to help you understand the concepts being presented in this course. You should use the scientific method to document the results of your experiments. The scientific method includes techniques for investigating, acquiring new knowledge, or correcting and integrating previous knowledge.

1. **Purpose:** What is your goal? What do you want to answer? Example: I would like to know what phase water is at room temperature.
2. **Hypothesis/Prediction:** What do you think will happen in this experiment? Example: I believe that water is liquid at room temperature.
3. **Experiment:** Test the hypothesis with systematic observations, measurements, and laboratory techniques.
4. **Analysis:** Determine what the results of the experiment show and decide on the next actions to take.
5. **Conclusion:** Describe what the results of the experiment show and the next actions to take.

As we do experiments, we will use this experimental method to document our findings.

Now that you have read this module and answered the "On Your Own" questions, it is time for you to shore up your new skills and knowledge with the practice problems and review questions at the end of this module. As you go through them, check your answers with the solutions provided and be sure you understand any mistakes you made. If you need more practice problems, you can find them in appendix B. Once you are confident in your abilities, take the test. If you do not score at least 70% on the test, then you should probably review this module before you proceed to the next one.

SUMMARY OF KEY EQUATIONS AND TABLES IN MODULE 1

Equation 1.1: $°C = \frac{5}{9}(°F - 32)$ Converting °F to °C

Equation 1.2: $K = °C + 273.15$ Converting °C to K

Table 1.1: Physical Quantities and Their Base Units

Table 1.2: Common Prefixes Used in the Metric System

Table 1.3: Relationships between English and Metric Units

Table 1.4: Examples of Significant Figure Rules

ANSWERS TO THE "ON YOUR OWN" QUESTIONS

1.1 $\frac{9{,}321\ \cancel{\text{g}}}{1} \times \frac{1\ \text{kg}}{1{,}000\ \cancel{\text{g}}} = \mathbf{9.321\ kg}$

1.2 $\frac{0.465\ \cancel{\text{L}}}{1} \times \frac{1\ \text{mL}}{1{,}000\ \cancel{\text{L}}} = \mathbf{465\ mL}$

1.3 $\frac{724.0\ \cancel{\text{cm}}}{1} \times \frac{0.01\ \text{m}}{1\ \cancel{\text{cm}}} = \mathbf{7.240\ m}$

1.4 $\frac{8.465\ \cancel{\text{sl}}}{1} \times \frac{14.59\ \text{kg}}{1\ \cancel{\text{sl}}} = \mathbf{123.5\ kg}$

1.5 $\frac{6.1236\ \cancel{\text{L}}}{1} \times \frac{1\ \text{gal}}{3.78\ \cancel{\text{L}}} = \mathbf{1.62\ gal}$

1.6 $\frac{1{,}500\ \cancel{\text{mL}}}{1} \times \frac{0.001\ \cancel{\text{L}}}{1\ \cancel{\text{mL}}} \times \frac{1\ \text{kL}}{1{,}000\ \cancel{\text{L}}} = \mathbf{0.0015\ kL}$

1.7 $\frac{2\ \cancel{\text{km}}}{1} \times \frac{1{,}000\ \cancel{\text{m}}}{1\ \cancel{\text{km}}} \times \frac{1\ \text{cm}}{0.01\ \cancel{\text{m}}} = \mathbf{200{,}000\ cm}$

1.8 $\frac{.01\ \cancel{\text{Mg}}}{1} \times \frac{1{,}000{,}000\ \cancel{\text{g}}}{1\ \cancel{\text{Mg}}} \times \frac{1\ \text{mg}}{0.001\ \cancel{\text{g}}} = \mathbf{10{,}000{,}000\ mg}$

1.9 $\frac{0.00555\ \cancel{\text{hr}}}{1} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{hr}}} \times \frac{60\ \text{sec}}{1\ \cancel{\text{min}}} = \mathbf{19.98\ sec}$

That is not a long time to hold one's breath. So we would not be impressed.

1.10 $\frac{0.0091\ \cancel{\text{kL}}}{1} \times \frac{1{,}000\ \cancel{\text{L}}}{1\ \cancel{\text{kL}}} \times \frac{1\ \text{mL}}{0.001\ \cancel{\text{L}}} = 9{,}100\ \text{mL} = \mathbf{9{,}100\ cm^3}$ (mL and cm^3 equivalent)

1.11 The relationship between m and mm is easy:

$$1\ \text{mm} = 0.001\ \text{m}$$

To set up the conversion, we start with:

$$\frac{32\ \text{m}^2}{1} \times \frac{1\ \text{mm}}{0.001\ \text{m}}$$

This expression *does not cancel m²*. There is an m^2 on the top of the first fraction and only an m on the bottom of the second fraction. To cancel m^2 (which we must do to get the answer), we have to square the conversion fraction:

$$\frac{32\ \text{m}^2}{1} \times \left(\frac{1\ \text{mm}}{0.001\ \text{m}}\right)^2$$

Then we get:

$$\frac{32\ \cancel{\text{m}^2}}{1} \times \frac{1\ \text{mm}^2}{0.000001\ \cancel{\text{m}^2}} = \mathbf{32{,}000{,}000\ mm^2}$$

1.12 (a) All 3 nonzero digits are significant figures, as are both zeros. One 0 is between 2 significant figures, and the other is at the end of the number to the right of the decimal. There are **5 significant figures**.

(b) The first 3 zeros are not significant because they are not between 2 significant figures. The 6 is a significant figure, as is the last 0 because it is at the end of the number to the right of the decimal. So there are **2 significant figures**.

(c) All digits are significant figures here. The first 2 zeros are between significant figures, and the last 0 is at the end of the number to the right of the decimal. Therefore, there are **6 significant figures**.

(d) All digits are significant figures. The 0 is between 2 significant figures. There are **5 significant figures**.

(e) All the zeros are not significant in this number. **There is 1 significant figure**.

1.13 **(a) 2.6089×10^7** **(b) $1.2000000003 \times 10^{10}$**
(c) 9.870×10^{-5} **(d) 9.80×10^{-1}**

1.14 **(a) 345,600,000,000,000** **(b) 1,234.1**
(c) 0.0000345 **(d) 0.310**

1.15 To solve this one, we simply need to use equation 1.1:

$$°\text{C} = \frac{5}{9}(°\text{F} - 32)$$

$$°\text{C} = \frac{5}{9}(98.6 - 32)$$

$$°C = 37.0$$

Our measurement starts with 3 significant figures, and the other numbers in the equation are exact, so we must end up with 3 significant figures. The answer is **37.0°C**.

1.16 This one requires that we use algebra to rearrange equation 1.1 so that we can solve for °F:

$$°F = \frac{9}{5}(°C) + 32$$

$$°F = \frac{9}{5}(180.5) + 32$$

$$°F = 356.9$$

Since 180.5 has 4 significant figures and everything else in the equation is exact, our answer is **356.9°F**.

1.17 The only way we can convert to Fahrenheit is if we have a temperature in Celsius. Before we can get the answer, we must first convert 0.00 K to degrees Celsius by rearranging equation 1.2:

$$°C = K - 273.15$$

$$°C = 0.00 - 273.15 = -273.15$$

Since we are subtracting, we look at precision. The original measurement goes out to the hundredths place, as does 273.15. Therefore, our answer should go out to the hundredths place. Now we can convert to Fahrenheit:

$$°F = \frac{9}{5}(°C) + 32$$

$$°F = \frac{9}{5}(-273.15) + 32$$

$$°F = -459.67$$

Since 273.15 is the only number in the equation that is not exact, the answer must have the same number of significant figures. The answer is **–459.67°F**.

STUDY GUIDE FOR MODULE 1

REVIEW QUESTIONS

1. Which of the following contains no matter?
   a. A baseball
   b. A balloon full of air
   c. Heat
   d. A light ray

2. List the base metric units used to measure length, mass, time, and volume.

3. In the metric system, what does the prefix *milli-* mean?

4. All conversion factors, when in the form of a fraction, must equal __________.

5. Which has more liquid: a glass holding 0.05 kL or a glass holding 12,000 mL?

6. How long is the bar in the picture below?

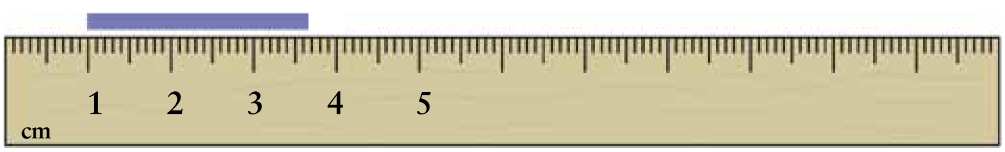


Illustration by Megan Whitaker

7. Two students measure the mass of an object that is known to be 50.0 grams. The first student measures the mass to be 49.8123 grams. The second measures the mass to be 50.1 grams. Which student was more precise? Which student was more accurate?

8. Explain what a significant figure is.

9. How many significant figures are in the following numbers?
   a. 120350 b. 10.020 c. 0.000000012 d. 7.20×10^2

10. A student measures the mass of object A to be 50.3 grams and measures the mass of object B to be 200.24 grams. She then reports the combined mass to be 251 grams. Is this student correct? Why or why not?

11. What would be the units on the following calculations? You do not have to do the math since this question only wants to know the units.
    a. 8 cm + 2 cm =
    b. 4 g ÷ 2 mL =

12. Which answer for question 11 will be a derived unit?
13. What are the 2 basic rules for using scientific notation?

14. Which is colder: 50.0 grams of water at 0.00°C or 50.0 g of water at 32.00°F?

PRACTICE PROBLEMS

Be sure to use the proper number of significant figures in all of your answers!

1. Convert 2.4 mL into L.

2. Convert 69.00 km into m.

3. Convert 0.091 kg into cg.

4. If an object has a volume of 69.2 mL, how many kL of space does it occupy?

5. A box is measured to be 23 cm by 45 cm by 38 cm. What is its volume in cubic meters?

6. A nurse injects 71.0 cc of medicine into a patient. How many liters is that?

7. Convert the following decimal numbers into scientific notation:
   a. 12.45000
   b. 3,040,000
   c. 6,100.500
   d. 0.001234

8. Convert the following numbers back into decimal:
   a. 6×10^{9}
   b. 3.0450×10^{-3}
   c. 1.56×10^{21}
   d. 4.50000×10^{-7}

9. Convert 85.6°C into Fahrenheit.

10. The temperature of the moon during its day is 396 K. What is that in Celsius? In Fahrenheit?

11. The average low temperature of International Falls, MN, in January is −7.0°F. What is that in °C?