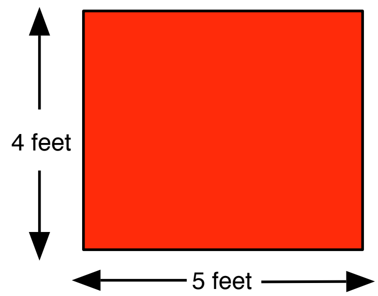
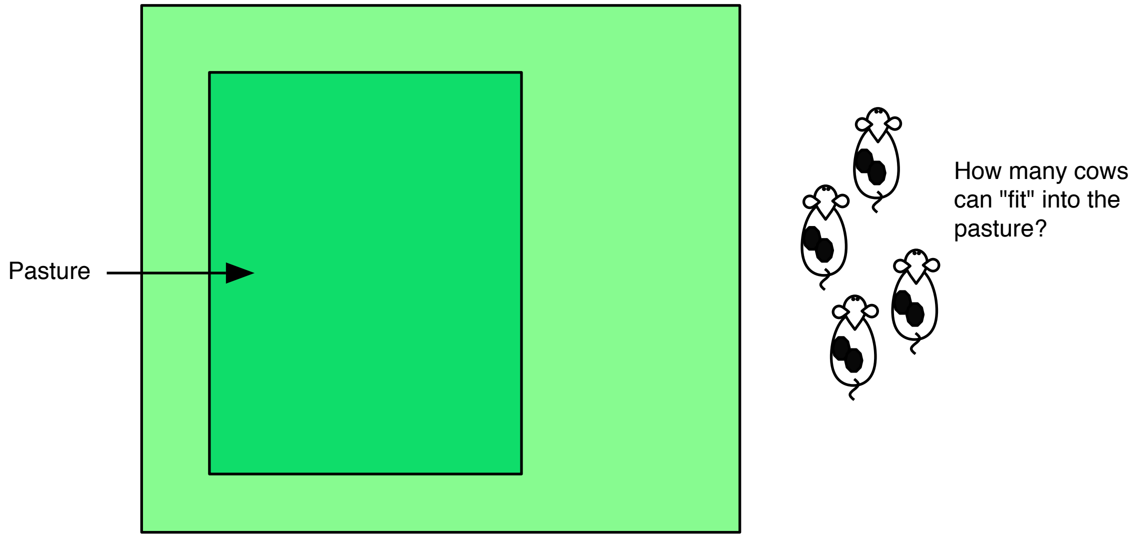


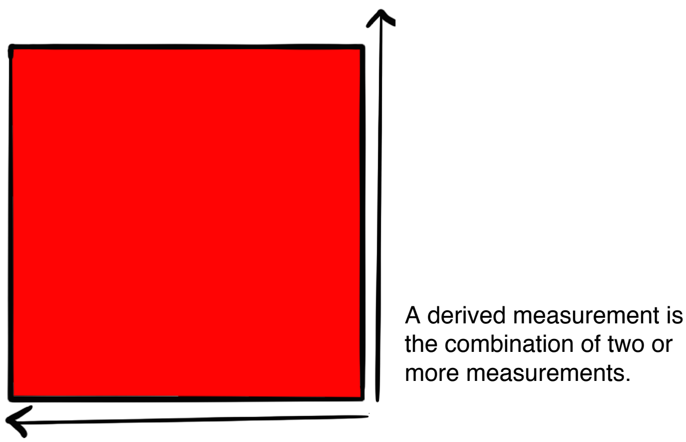
Lesson 2: Finding Surface Area

In Lesson 1, we introduced you to the concepts of base measurements. You learned that there were three base measurements: length, mass and time. In Lesson 1, our focus was on length. Before we move to our second base measurement in the next lesson (which is mass), let's take a look at our first set of *derived* measurements. Derived measurements are those made by doing a math operation with a set of *base* measurements. This may sound complicated, so let's look at an example to show you that it's really rather simple.

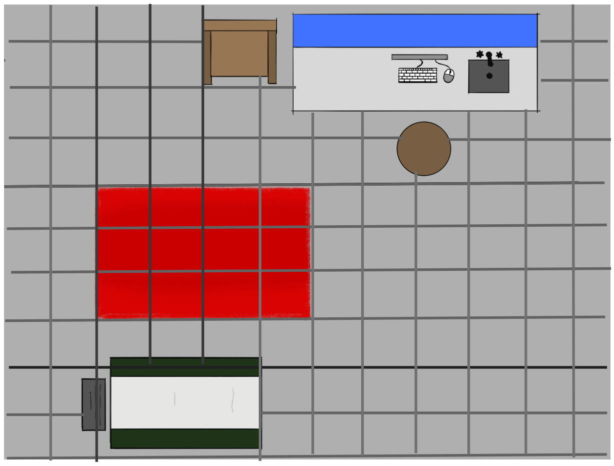
Refer back to the illustration we used in Lesson 1 when we were talking about purchasing a piece of land. We said you needed to put a fence around the land to allow your cows to eat grass in the pasture. Let's pretend now that you learn it's important to not put too many cows on the pasture which might result in damage to the grass. You learn it's recommended to allow a certain amount of space for each cow on the grass. This amount of space necessary for each cow is called surface area.



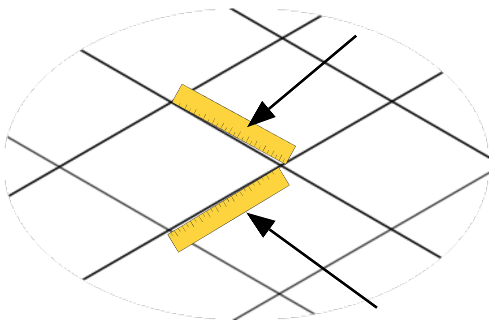
Area is an amount of space which is measured in two directions or two dimensions. The measurements taken are two length measurements. Recall that length is a *base* measurement and in our illustration we are going to perform an operation with these two measurements. The amount of area we find will be a *derived* measurement (it resulted from an operation of two or more base measurements.)



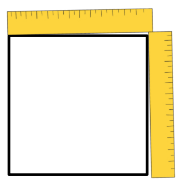
Before we determine how to measure the area of this portion of pasture, let's look at a simpler situation. Look at the diagram below. This in an overhead view of a doctor's exam room. Note that the floor of this room is covered with square floor tile.



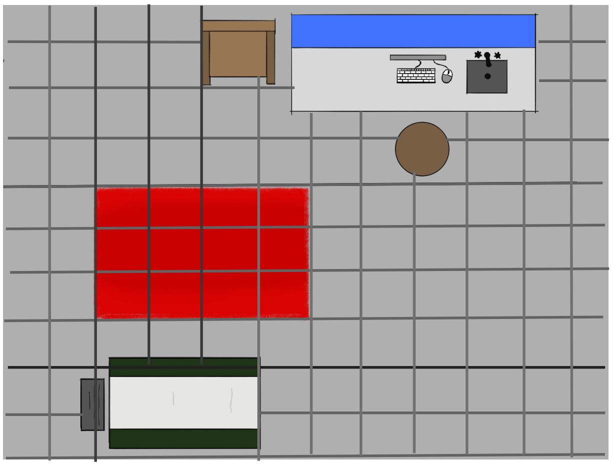
Let's take a portion of this floor and examine each floor tile. If you look closely below you can see that alongside the edge of one of the tiles is a 12-inch (or one foot) ruler. Note another tile with a similar ruler along an adjacent edge of a tile. We can say that the distance (length) along each side of each tile is 12 inches or one foot. We can then say that each tile covers one square foot of area. It's one foot by one foot or 1 foot x 1 foot which equals 1 foot squared. Each floor tile covers an area of one square foot.

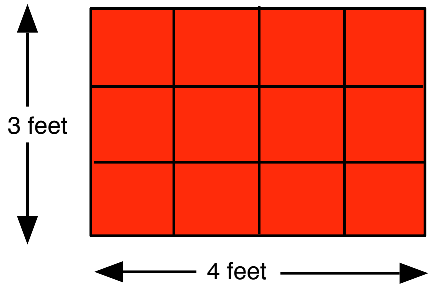


Each floor tile measures 1 foot on each edge. We can say that the surface area of each tile is one square foot or 1 ft^2.

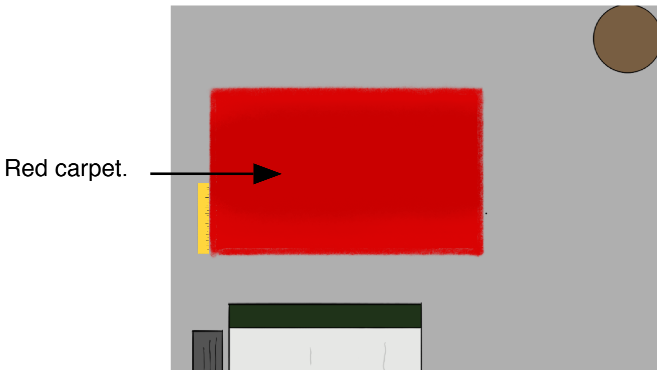


Now, look at the set of floor tiles in the diagram on the next page. Focus your attention on the red tiles. Again, let's assume that the distance along each edge of the tiles is one foot. Note that in our set of red floor tiles that we have four columns of tiles (sets going up and down) with each column having three tiles. We can say that we have four sets of three tiles or 4 times 3, which equals 12 tiles. Since each tile is one square foot, we can say we have 12 square feet of tiles or 12 ft^2.



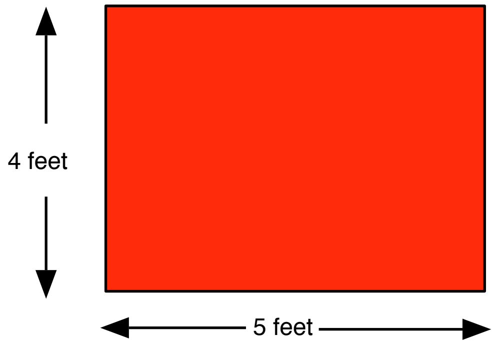


Now, take a look at the diagram below. Note that it shows a similar room, however, the room no longer has floor tiles covering the floor. Instead, there's a piece of red carpet on the floor. Let's suppose you would like to know how many square feet are in this piece of carpet. How would you go about finding this area?



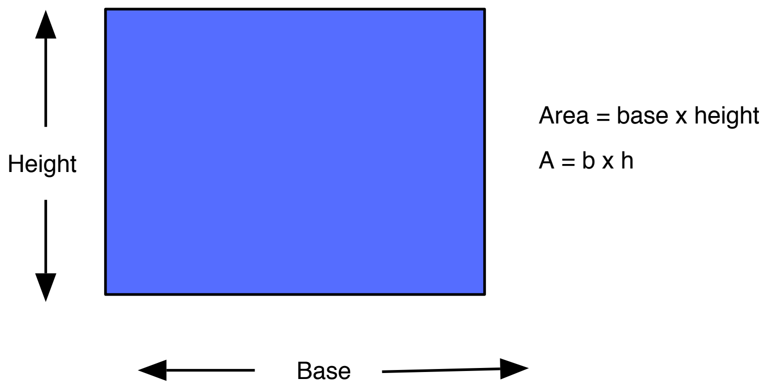
Refer back to our calculation of the area of the red floor tiles. Note that we multiplied the distance across the "bottom" edge of the tiles (how many columns we had) times the "height" of each column. We can do the same operation to find the area of the piece of carpet.

To do so, we can take the ruler and measure how many feet there are along the "bottom" edge of the carpet. We then find the "height" of each "column." In this case, we can see that the "bottom" edge of the carpet measures 5 feet and the "height" measures 4 feet. By multiplying the length along the bottom by the height of each column, we can see that the number of square

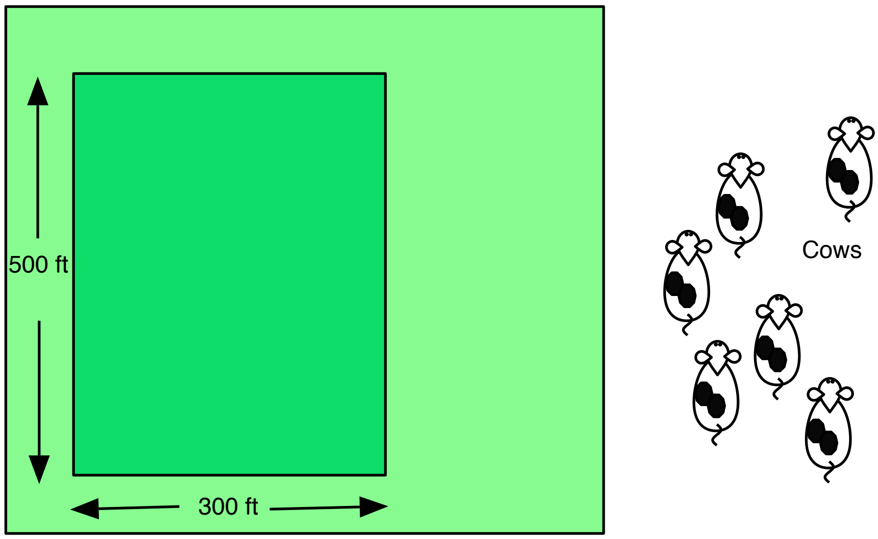


feet in the piece of carpet equals 20 square feet. Another way to write the derived measurement is 20 ft^2. Keep in mind that this is a *derived* measurement in that it comes from a math operation completed with two or more *base* measurements.

Often the "bottom" measurement we've been looking at in these examples is called the base, as it's the supporting portion of the structure above. Therefore, when we measure the area of a square or rectangle we can say that the area equals the base times the height of the shape. Using symbols to represent the measurements we can say A = b x h or A = bh (A = area, b = base and h = height).

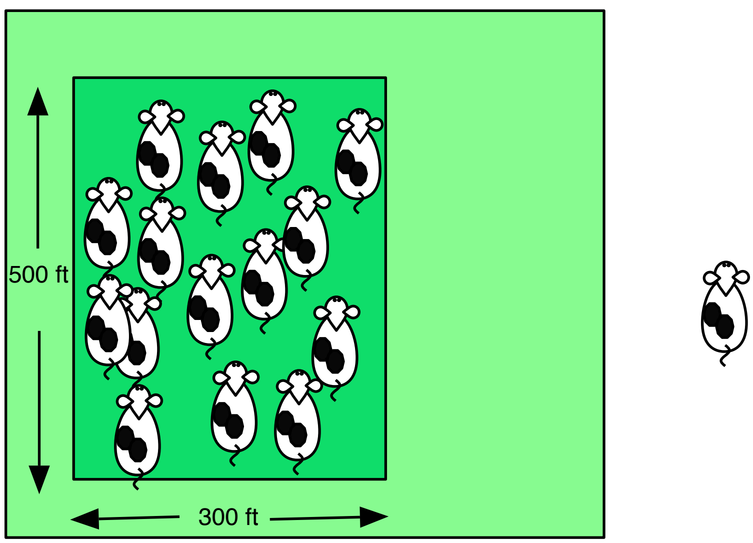


Let's go back now to our cows in the pasture illustration. Look at the diagram below. Note that we have outlined the area of the land which will become the pasture for the cows. Note that the length of the base of the pasture has been measured to be 300 feet. Note that the "height" of the pasture is 500 feet. Based upon our discussions above, how many square feet make up the



pasture? If we were to lay out floor tile over the grass, we'd have three hundred columns of tiles each being 500 tiles "high." Therefore we have 300 feet x 500 feet = 150,000 square feet or 150,000 ft^2.

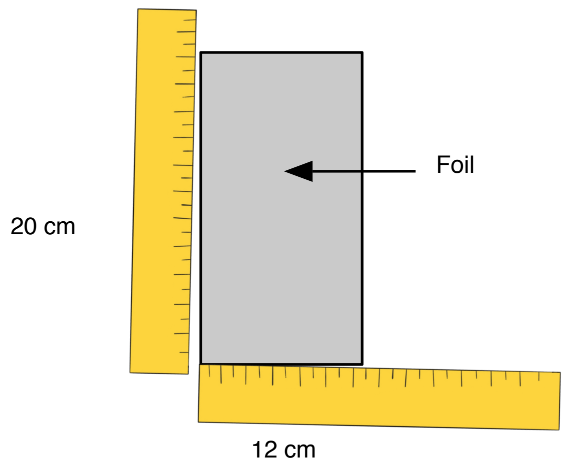
If we had learned that each cow requires 10,000 square feet of pasture, we could take our total square feet of pasture (150,000 square feet) and divide it by the amount each cow requires (10,000 square feet): 150,000/10,000 = 15. So, theoretically we could place 15 cows on our pasture.



Fifteen cows could "fit" into our pasture based upon our calculation of the surface area of the pasture.

So to review, we learned that to find the surface area of a square or rectangular shape, we multiply the length of the base of the shape times the height of the shape (knowing that these are columns of square units within the shape).

Let's look now at another example. In this case, instead of using the English system of measurement, let's use the SI system and we'll look at an object much smaller than a piece of land. Let's pretend you have a flat, rectangular piece of aluminum foil. You've been asked to determine the area of this piece of foil. Your measuring instrument is a ruler that is divided into centimeters.

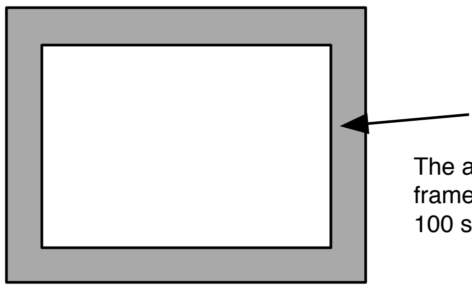


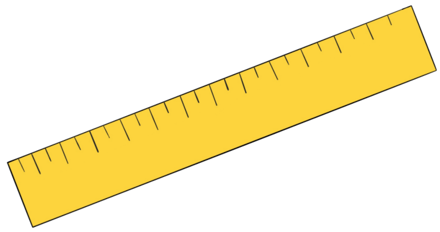
Note that the base of the piece of foil has been found to be 12 cm in length. Note that the height of the rectangle is 20 centimeters. We can also say each column has a height of 20 centimeters. To find the area of the piece of foil, we multiply these two values (base times height): 12 cm x 20 cm = 240 square centimeters. The surface area of the piece of foil is 240 square centimeters or 240 cm^2.

Let's move on to the design challenges for this lesson.

Challenge 1: This challenge will be very similar to Challenge A of Lesson 1. You will need to construct a picture frame like you did before, however, this picture frame must have an opening that is exactly 120 square centimeters. Once you have it completed have your mom, dad or teacher examine your work. Take your time and draw a good plan first on paper or using a computer program. Then remember, "measure twice, cut once."

Challenge 2: In this challenge, you'll make yet another picture frame. However, instead of having a specific opening area, for this frame the total area of the flat surface of the sides of the frame must be exactly 100 square centimeters. After constructing the frame, submit your creation to the crash test you utilized in Lesson 1. For this lesson, your frame must be able to survive being dropped at least 3 meters from the floor onto a hard surface. Once completed, decorate your frame and find a nice photo or piece of artwork for which to use it.





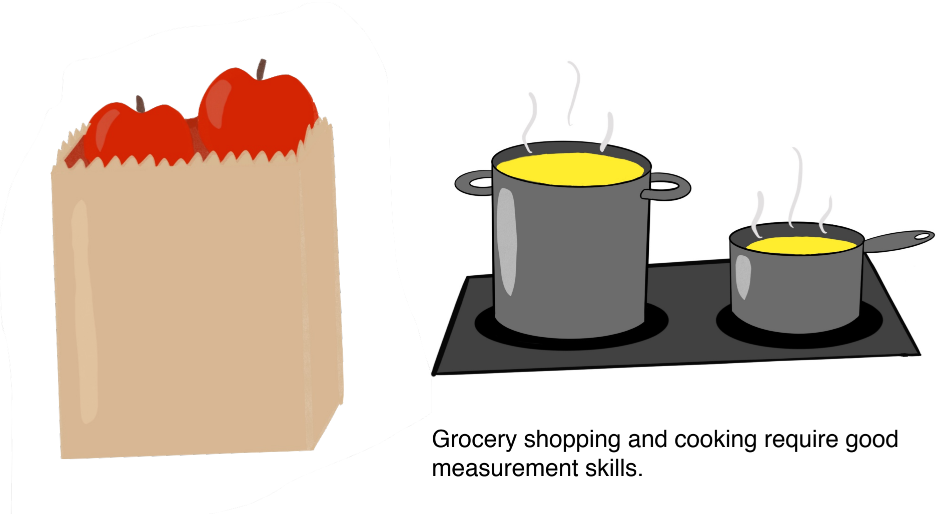
Lesson 1: Introduction to Measurement and Length

Welcome to your course in physical science. The first thing we need to do is define what we mean by physical science. It's sometimes easier to define physical science by telling what it is not! Physical science is the study of those things in our world which are NOT alive. Life science and biology are courses which focus on living things. In physical science our focus will be on the non-living things.

We'll look at things like measurement, energy, forces and simple machines which make up the non-living parts of our world. These non-living things definitely do affect us as living things and that's why it's a great idea to understand them better. So, our goal in this physical science course is to explore science concepts which primarily focus on non-living things.

We'll begin our study by looking at concepts of measurement first. Think about this question: why do we need to understand how to measure things? Write some ideas here:

You may have written things like, "It's good to know how to measure so when you cook something, you get the recipe correct." Or, "It's good to know how to measure so when you build something, the parts fit together right." If one of your jobs around the house is helping with buying groceries for your family, you know it's important to pay fair prices at the supermarket. Understanding how quantities of groceries are measured helps you make sure you're getting the amount of goods for which you've paid.



Grocery shopping and cooking require good measurement skills.

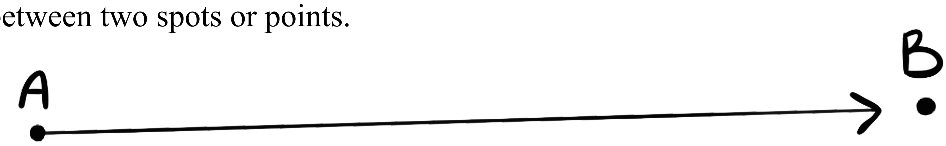
As an adult, you may enter into a career where you sell products to others. A great example of this is a farmer or rancher. Because almost all farm products are sold by the pound, understanding how to correctly weigh your products is vitally important to the success of your farming business.

Marketing products you make requires that you understand how to measure them.

Another career example is the job of a nurse or pharmacist. These persons must correctly measure dosages of medications every day to ensure their patients get the response they expect from the medication. Additionally, doctors have to interpret the results of tests completed on their patients so understanding how these results are reported in regard to the units "behind" the numbers is very important. If you stop and think about it, almost everyone needs to understand how "stuff" in our world is measured.

Doctors, nurses and pharmacists must use accurate measurement skills on a daily basis to ensure that their patients receive excellent care.

In this lesson we're going begin by studying the measurement of length. Length can be defined as how long it is from one spot to another. So, we might have spot A and then spot B. The length would be the distance between these two spots or points. These spots might be two points on a piece of paper or two locations in a field or on a map. Or they could be at two locations on an object, like top and bottom edges or distance from right side to left. So, length is defined as the distance between two spots or points.

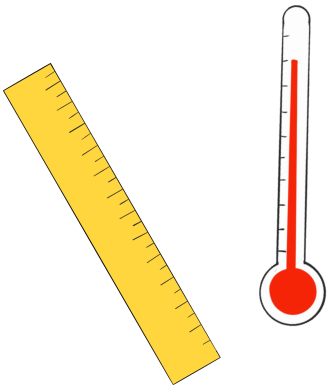


Let's pretend that you just bought a piece of land with some pasture on it. You have some cows you'd like to move there to graze on the pasture. To keep the cows on your land (and not someone else's) it would make sense to build a fence around your property. In order to build the fence, you would have to know how much wire, how many fence posts and other supplies it would take to build the fence. To know these amounts, you'd have to know the length of the fence or at least how much of your land that you want to enclose with the fence.

This is an aerial view of pastures and corn fields. Being able to make accurate measurements of these fields allows a farmer to calculate supplies and equipment he or she might need in order to have success in farming these sections of land.

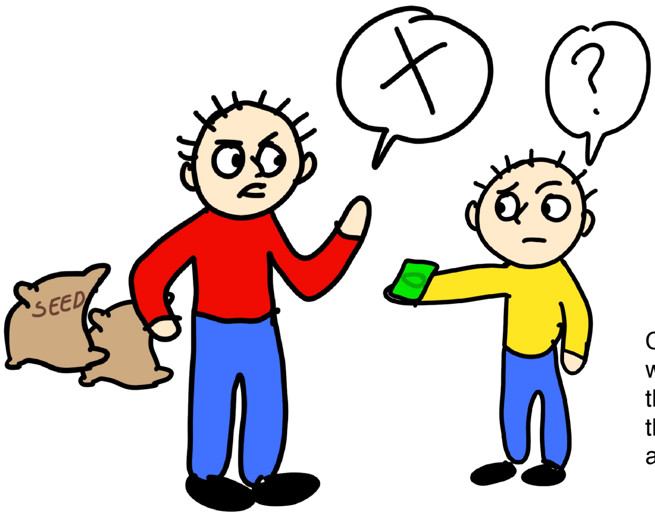
This brings up our first point that we must consider when we talk about measuring length (or, in actuality, any kind of measurement we take whether it be length or weight or temperature or intensity): to measure something means we are comparing what we're intending to measure to some sort of standard unit. This standard is a unit that "everyone" has agreed upon to use. An example of a standard used to measure length could be inches or feet or miles. When we measure weight, a standard could be ounces or pounds. What standards do we use when we measure the temperature of something? If you said degrees Fahrenheit or Celsius, you'd be correct. So, measuring something infers that we are comparing an unknown quantity to a known or standard quantity (standard unit).

When we make measurements of things, we compare the unknown amount (amount we're trying to find) with that of a known standard amount. With the measurement of length we might use a ruler on which the standard units are inches. With temperature, we might use a thermometer on which the standard units of measure are degrees.



In today's world, these standard units may seem second nature to you. In the United States, we are all familiar with long distances being measured in miles and shorter distances being measured in yards, feet or inches. However, if you've ever traveled to other countries, you have likely encountered that distances are measured using units other than feet or miles. These distances may be measured in meters or kilometers.

This brings up a second point about measuring things: standards have to be agreed upon by folks using those standards. Agreement between groups of people regarding the standard by which a "thing" was to be measured has not always been the case. In fact, in the fifteenth and sixteenth centuries, in France alone, it was estimated that there were over 250,000 different standards of measuring units. This vast array of units, as you might imagine, caused many disruptions in trade and also allowed for cases of fraud and, consequently, conflict to be quite high.

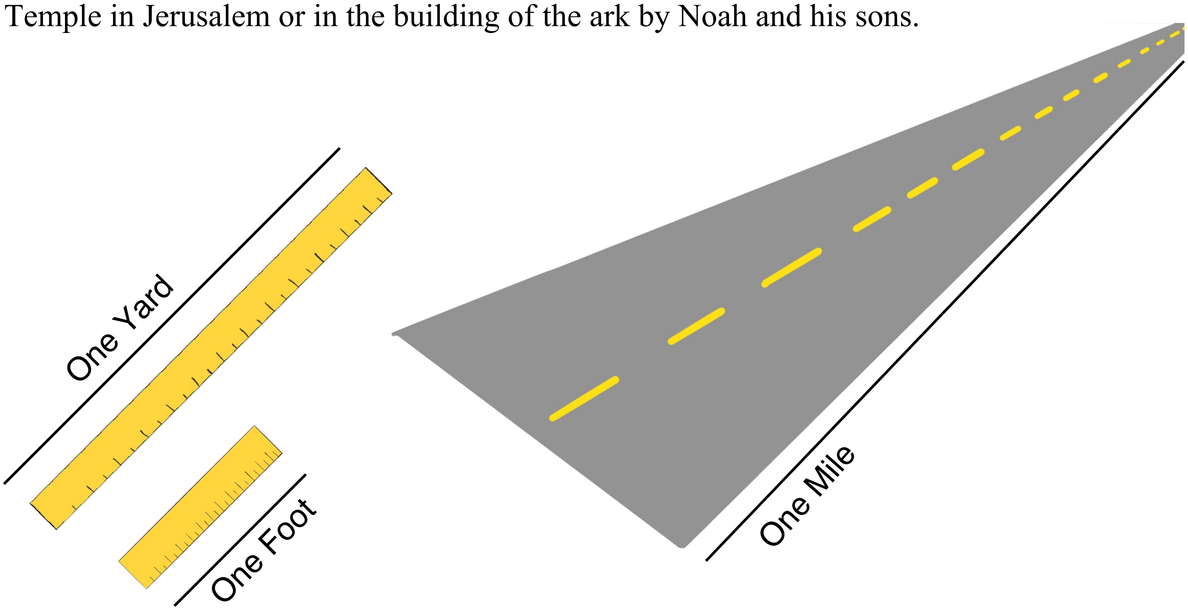


Conflicts can quickly arise when persons don't agree upon the standard of measurement they are using when buying and selling goods.

To combat these problems with establishing at least a nation-wide standard for measurement, government officials have stepped in to mandate that certain units be used. Eventually, these standards of measurement have spread across larger regions which has resulted in greater ease of commerce between individuals and countries. However, *adoption* of these standards may not always be the case. For example, while almost all nations of the world utilize the metric system of measurement, the United States is one of only three countries to fully adopt the metric system as its primary standard of measurement. Consequently, issues remain with conversion from one system to another.

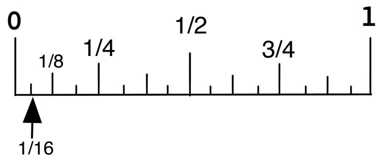
So, we've said that measurement is a comparison of an unknown amount to a known standard unit and that it's a very good idea to have persons agree upon the quantity of the standard amount. Let's go back now to our discussion of length.

We've said that length is a measure of the distance between two spots or points. Let's look now at the currently accepted standard units for length in the United States. You are likely very familiar with the system which utilizes inches, feet, yards and miles as the standard of measurement. This system is known as the English system. Most school rulers you find represent a foot which is thought by some to have had its origin in the cubit which was used by ancient Egyptians. You may have read about these cultures using the cubit in the description of the Temple in Jerusalem or in the building of the ark by Noah and his sons.



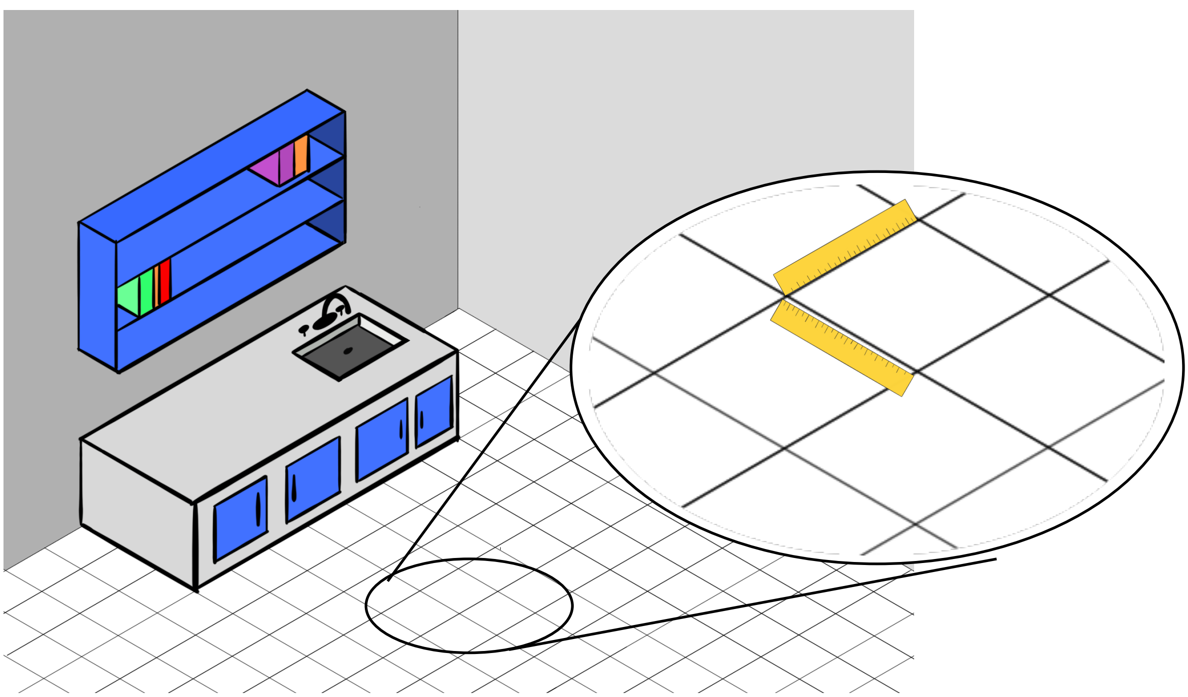
The foot is divided into twelve equal portions known as the inch. Therefore, twelve inches equal one foot. Three feet when placed end-to-end make up one yard. We can also say that 36 inches (3 x 12 inches) equal one yard. When 5280 feet are lined up end-to-end, we have one mile.

We can also take inches and divide them into smaller pieces to make the inch more useful for measuring smaller lengths. If we divide an inch into four equal parts, we'd be using one-fourth inch units. If we divided it into eight equal parts, each portion would be an eighth of an inch. If we divided it into sixteen equal parts, each part would be a sixteenth of an inch and so on.



Not drawn to scale.

If you're ever in need of measuring the length of something and don't have a ruler or yardstick handy, the distance from the tip of your index finger to your first joint on your finger is approximately one inch. Also, the standard size for floor tiles used in public places like schools and hospitals is 1 foot by 1 foot. Lining up three tiles side-by-side can help you measure a yard.



Remembering the numerical values and comparisons between the inch, foot, yard and mile and then the smaller parts of a portion of an inch can be challenging. This is a disadvantage of using the English system of measurement and where the metric system can be much more practical to use. The metric system is officially known as the SI or International System of measurement.

Unlike the English system of measurement, the metric system relies on the standard units being in multiples of tens. Because of this, the metric system is often referred to as a decimal system. The metric system has identified base units for length, mass (sometimes referred to as weight which we'll discuss in our next lesson) and time. The base unit for length is the meter. The base unit for mass is the gram. The base unit for time is the second. Multiples of these base units are in sets of tens and have a prescribed set of prefixes. On the chart below, you'll find several of the more commonly used prefixes. Let's take a closer look at them now.

If we begin with the base unit for length as the meter and take ten of those lined up end-to-end,

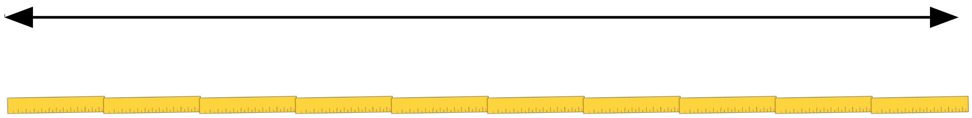
Metric Prefix Table

Prefix	Symbol	Multiplier	Exponential	
tera	T	1,000,000,000,000	10^{12}	
giga	G	1,000,000,000	10^{9}	
mega	M	1,000,000	10^{6}	
kilo	k	1,000	10^{3}	
hecto	h	100	10^{2}	
deca	da	10	10^{1}	
UNIT	NONE	1	10^{0}	← BASE UNIT
deci	d	0.1	10^{-1}	
centi	c	0.01	10^{-2}	
milli	m	0.001	10^{-3}	
micro	m	0.000001	10^{-6}	
nano	n	0.000000001	10^{-9}	
pico	p	0.000000000001	10^{-12}	

Example of how to read the table: If a unit has the prefix giga (denoted by adding G before the unit symbol), that unit is 1,000,000,000 (or 10^9) times bigger than the original unit. For example, a gigawatt (GW) is 10^9 times as big as a watt.

this length is known as a decameter. Think about a decade being a set of ten years. Therefore, a decameter is the same as 10 meters.

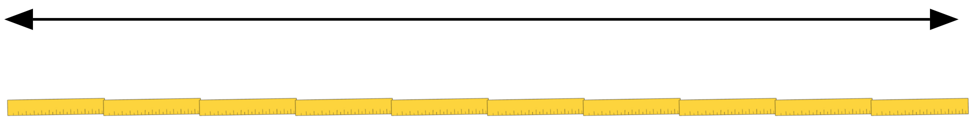
One decameter



Ten meters

If we take ten decameters and line them up end-to-end (which is 10 x 10 or 100 meters) we have a hectometer. Look at the diagram here to see this relationship.

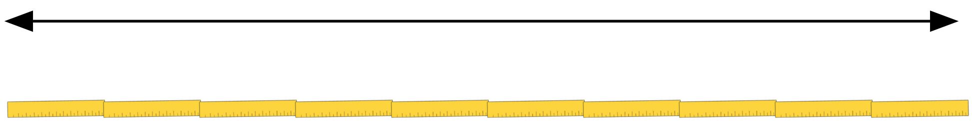
One hectometer



One hundred meters

Then, if we line up 10 hectometers (10 x 10 hectometers or 10 x 10 x 10 meters = 1000 meters) we'd have a kilometer. So, there are 1000 meters in one kilometer!

One kilometer

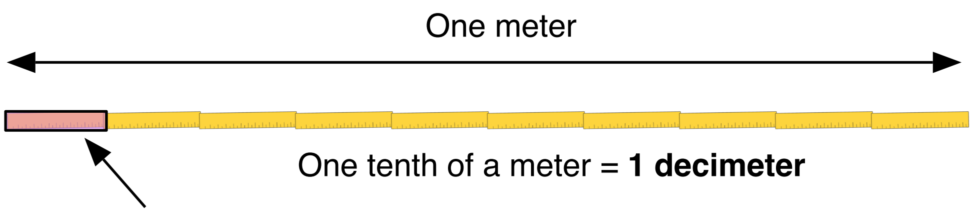


One thousand meters

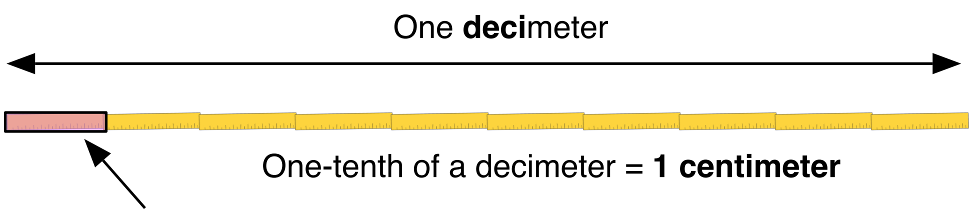
Take a look at the chart again to see the prefixes used for multiples of meters beyond the kilometer. Some of these prefixes may sound familiar to you in that they are used to describe the amount of "space" or memory found on electronic devices like your computer or cell phone. In these cases, the byte is the base unit.

As we mentioned above with the English system of measurement, the SI system is also useful when we need to measure very small distances. When dividing the base unit of length, the meter, into smaller pieces, another set of prefixes is utilized. These prefixes designate parts of the meter in parts of tens or more precisely in this case, multiples of tenths, hundredths, thousandths, etc.

If we take one meter and divide it into ten equal parts (see diagram below), each of these parts is known as a decimeter. We can say that one-tenth of a meter is a decimeter. We can also say that it takes 10 decimeters to make up one meter.



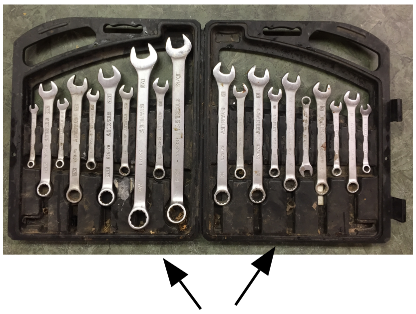
If we go one step further and divide each decimeter into ten equal parts, each of these parts is known as a centimeter. We can say that one-tenth of a decimeter is a centimeter. We can also say that it takes 10 centimeters to make up one decimeter.



Now, think for a moment. If it takes ten centimeters to make one decimeter, how many centimeters would there be in one whole meter? We have ten sets of ten, correct? This would make 100 total centimeters in a meter! We bring up this point because the prefix centi- refers to

100 as in century (100 years) or centurion (commander of 100 men in a military unit). Knowing that 100 centimeters are in a meter is very useful.

We'll go one step further in dividing meters because, like the centimeter, the next degree of division is frequently used in everyday life. Cars made outside the United States often require tools made for nuts and bolts in the metric system and the unit used is the millimeter. Car mechanics often have two sets of wrenches and sockets: one set with inches as the base unit and a second set with millimeters as the base unit.

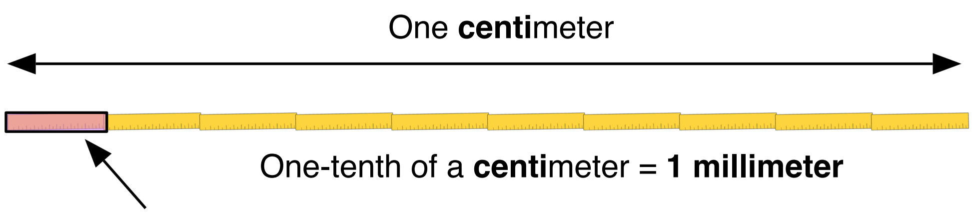


English system

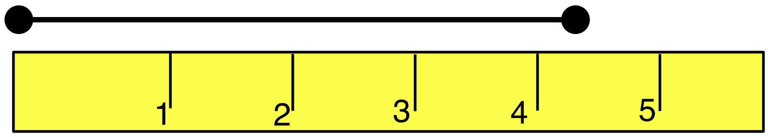
Metric system

Car mechanics often utilize two sets of wrenches. One set fits nuts and bolts in the English system (parts of inches) while the second set fits parts measured in the SI (metric) system.

If we take one centimeter and divide it into ten equal parts, each part is a millimeter. The prefix milli- means one-thousandth. So, if we have ten millimeters in each centimeter and there are 100 centimeters in one meter, we have 10 x 100 = 1000 millimeters in one meter. On most conventional meter sticks the smallest division is the millimeter. There are 1000 mm in a meter.



This brings up an important concept regarding how precise you can be when using measuring instruments. As we just mentioned, most meter sticks we have in today's world are made having the millimeter as the smallest unit. This means we can measure (with accuracy) to the nearest millimeter. We can, however, estimate beyond that measurement to a portion of a distance which happens to fall between two centimeter measurements. For example, suppose you've been asked to measure the distance between two points. When you place your meter stick to connect the two points, you find that the distance does not exactly end on one of the centimeter marks. You can then estimate to a degree beyond the centimeter measurement.



Not to scale.

Suppose your meter stick only had decimeter marks made on it. Consequently, you can be quite confident of a measurement which "lands" directly upon one of these decimeter marks. However, while it is permissible to estimate the length of distance which does not fall on one of these marks, your level of confidence in the accuracy of your result is decreased.

Don't let this discussion confuse you. Our purpose here is to make the point that we are definitely limited by the measuring tools we are provided with to make measurements.

Let's apply some of the concepts we've learned so far and practice measuring some lengths of lines. Using a ruler or meter stick, measure each line provided below. If you are using a "well-used" ruler (possibly having some of the marks rubbed away from years of use or that the end of the ruler is no longer as "correct" as it once was), know that it's "okay" to begin measuring your line at a point other than the zero mark. Just note that it's the difference of the two points which creates the distance between the two end points of the line. After you make your measurements, refer to the next page to see the measurements we found for each line. For this first set of lines, use the English system of measurements (inches).

LINE 1 ______________________________ _____ inches

LINE 2 ____

_____ inches

LINE 3 ______ inches

LINE 4 ______ inches

Answers: Line 1: 3.0 inches Line 2: 5.0 inches Line 3: 1.5 inches Line 4: 3.5 inches

Now practice measuring these lines. Use the metric system of measurement (centimeters).

LINE 1 ______ cm

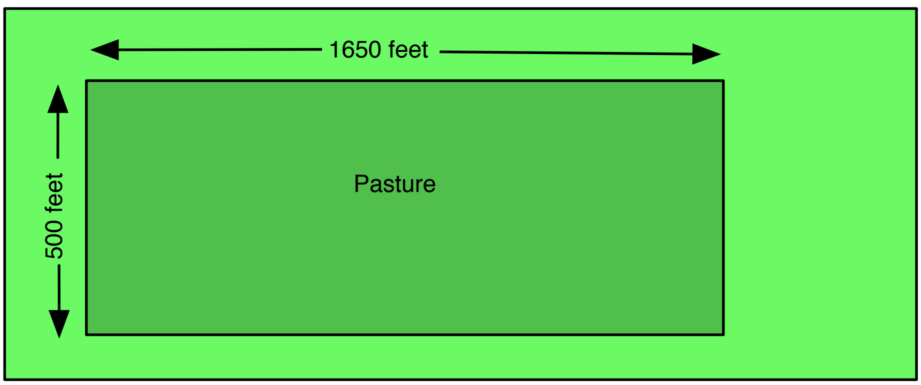
LINE 2 ______ cm

LINE 3 ______ cm

LINE 4 ______ cm

Answers: Line 1: 5 cm Line 2: 11 cm Line 3: 7 cm Line 4: 3.5 cm

Let's go back now to the example of building a fence around a pasture. Look at the diagram below which shows the dimensions of the pasture you intend to fence. How many feet of fencing will you need to fence this pasture?



Answer: 1650 + 500 + 1650 + 500 feet = 4300 feet.

Let's "switch gears" now and have *you* draw lines of specific lengths.

Draw a 3 inch line here:

Draw a 6 inch line here:

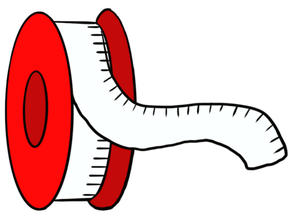
Draw a 12 cm line here:

Draw a 5 cm line here conected to a 7 cm line here:

Draw a straight line 5 cm longer than the line you just drew:

Have your mom, dad or teacher check your work.

Finally, know that the distances we need to measure may not always be in straight lines (or combinations of straight lines as you found in the previous exercise). Sometimes you may need to know the distance of a curved line. A cloth tape measure, like a seamstress may use, or piece of string can be useful for measuring a curved line. Carefully lay the string along the line and mark the beginning and ending points on the string. Then lay the string along your ruler or meter stick to find the length of the curved line.



A cloth tape measure makes measuring curved surfaces easier.

Let's pause now and review what we've learned in this lesson. We have learned that:

Physical science is the study of those things in our world which are NOT alive.

Measurement is important in studying non-living things.

Length can be defined as how long it is from one spot to another.

Measuring something means we are comparing what we're intending to measure to a standard unit.

Standards have to be agreed upon by persons using those standards.

The English system of length measurement utilizes inches, feet, yards and miles as the standard of measurement.

The metric system is officially known as the SI or International System of measurement.

The metric system relies on the standard units being in multiples of tens.

The base unit for length of the SI is the meter.

The base unit of the SI for mass is the gram and the base unit for time is the second.

Introduction to design challenges and labs:

In this course for each lesson you will find design challenges and/or labs. While these activities are optional for the course, you are highly encouraged to investigate and complete them. Let's look first at the design challenges.

The **design challenges** are projects in which you are challenged to create an object which meets certain specifications. These specifications are related directly to the concepts which were just presented in the lesson. They may also include concepts from previous lessons. These are fun, yet challenging projects and may require a good bit of time (and patience) to complete. We recommend you not place a deadline on them for completion, yet work efficiently to get the job done.

Supplies for these challenges can be just about anything you have around the house such as popsicle sticks, pipe cleaners, card stock, thread spools, soda straws or rubber bands. Items you can find at a craft store such as balsa wood sticks or strips, foam board, wooden dowels and wheels are highly recommended. Wood glue or hot glue to assemble these parts will also be necessary.

Simple tools such as scissors, a hand saw or drill will come in handy.

The labs, on the other hand, are activities similar to labs you have likely done in other science courses. They each have an objective or purpose which is fulfilled by gathering certain materials and equipment and then carrying out a prescribed procedure with the goal of experiencing an expected result. Like the design challenges, each may take a varying amount of time and effort to acheive the best results. Each lab requires materials you can find around your house or at your local grocery or hardware store.

For lesson 1, there are two design challenges. Each is relatively simple, yet provide you with opportunities to practice the concepts you've just learned about. We recommend you do them in order.

Design Challenge 1: In this challenge, you'll need to cut five lengths of wooden sticks. Pay close attention to the units you are being asked to cut. A good adage used by carpenters who build houses or furniture from wood is "measure twice, cut once" (meaning take your time and measure the specified distance two times, then make the cut). Doing so will greatly enhance your chances of an accurate cut. With each cut you make, your skill will be better and better.

Stick 1: cut a stick that's 4 inches in length.

Stick 2: cut a stick that's 6 ½ inches in length.

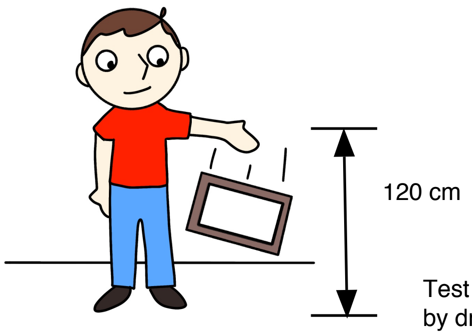
Stick 3: cut a stick that's 7 centimeters in length.

Stick 4: cut a stick that's 10 centimeters in length

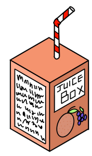
Stick 5: cut a stick that's 0.7 decimeters in length

Design Challenge 2: In this challenge, you will need to build frame for a photo or picture. The frame needs to have the following dimensions (dimensions is just a "fancy" word for measurement): the inside opening needs to be 15 centimeters from the left edge to the right edge. The opening needs to be 10.5 centimeters from the top to bottom edge. The frame needs to be sturdily built. The test for sturdiness is as follows: the frame can be dropped from a height of 120 cm to a solid surface and not break.

You are strongly encouraged to make a drawing of your project before you begin actually building the frame. Making the drawing from two views such as from above or from the side can be very helpful to visualize the ideas you have. These drawings can help you identify problems you have in your design *before* you start cutting any pieces of supplies. A computer drawing program such as the free Google Sketchup (www.sketchup.com) can help you make these drawings.

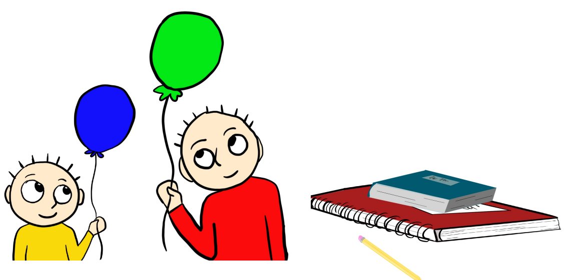


Test the sturdiness of your picture frame by dropping it from a height of at least 120 cm onto a hard surface.



Lesson 3: Finding the Volume of Regularly-shaped Objects

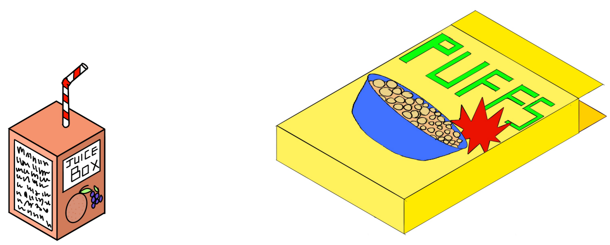
In Lesson 2, we introduced you to our first derived measurement which was surface area. Recall that with derived measurements, where we take two or more base measurements and, through the use of a math operation (adding, multiplying, dividing), we come up with a new meaningful measurement. In this lesson, we are going to introduce you to another derived measurement known as volume. By definition, volume is the amount of space something takes up. Objects in our world take up space. Your book and your pencil take up space. You and I take up space. Everything, even things that are liquids and gases, take up space and therefore have volume. The measure of how much space something takes up is its volume.



Everything in our world, whether it be a solid, liquid or gas takes up space and, therefore, has volume.

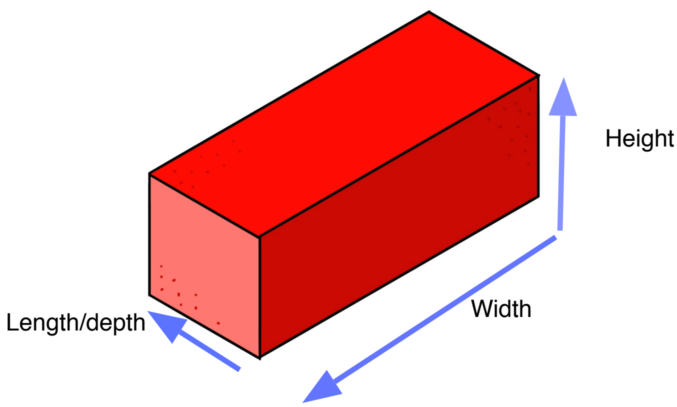
Recall from our discussion in lesson 2, we said that area was an amount of space measured in two dimensions. Volume is measured in three dimensions. Let's take a closer look by pretending you have a cardboard box and would like to know its volume.

Because boxes are usually made with flat surfaces that have measurable dimensions, we can find the volume of the box using derived measurements. We refer to these flat surfaces as being regular in shape. (In the next lesson, we'll look at techniques we can use to determine the volume of objects which do not have flat surfaces. These objects are referred to as having irregular surfaces.) While cardboard boxes are great examples of regularly-shaped objects, a rock or apple would be a good example of an irregularly-shaped object. Let's look first at the steps to find the volume of a regularly-shaped object.

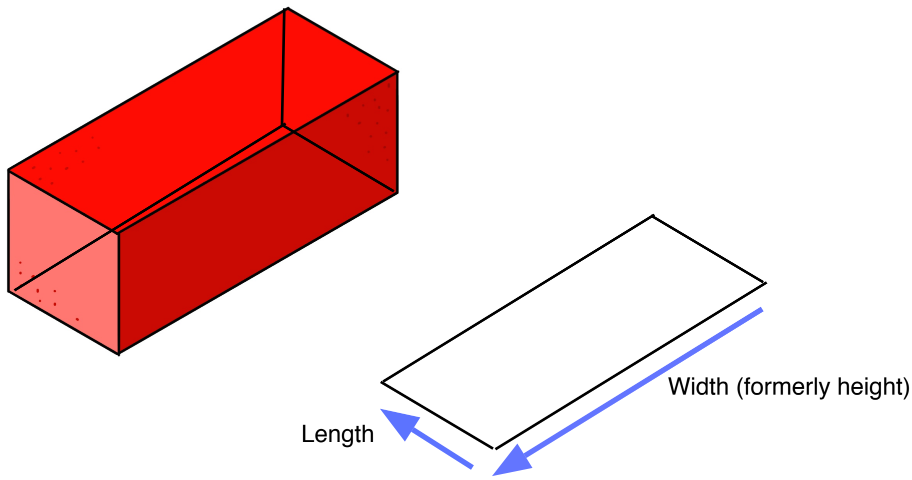


The boxes in which juice and cereal come are examples of regularly-shaped objects.

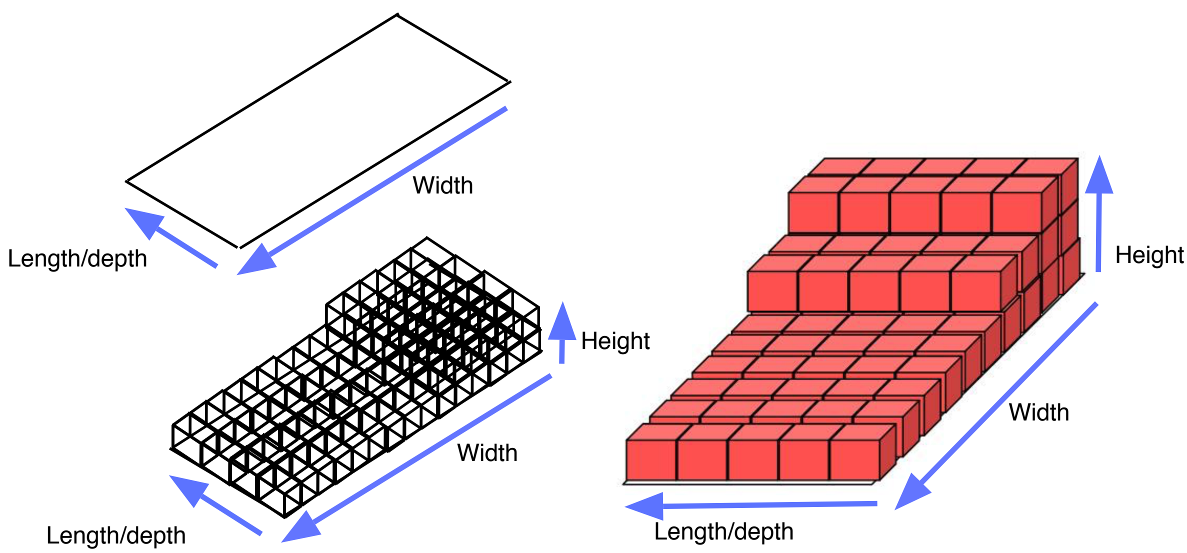
When we think about finding the volume of a regularly-shaped object, the first thing we must realize is that objects have three dimensions. These objects have the distance from left to right, front to back and then top to bottom. These measurements are conventionally identified as being the length, width and height of the object. The "length" measurement is also referred to as depth.



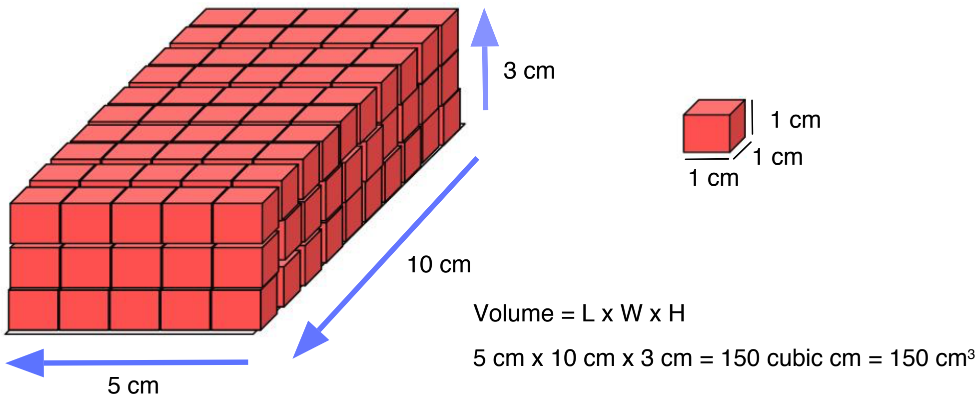
Let's focus first on the bottom or base of the box. Note that by multiplying the length by the width of the bottom of the object, we can get the area of the bottom of the object. In Lesson 2 we referred to these two measurements as the length and height of the shape. Let's rename "height" to "width" to reduce confusion.



Recall that this area would be presented in square units. If we use centimeters, these units would be a quantity of square centimeters. If we extend each of these squared units upward (the height of the object) we can essentially find out how many layers of cubic units exist in the object. Essentially, we are attempting to find out how many of these cubes, measured one unit on each edge, that can "fit" into our object. Look at this diagram to see how we can count these cubes.

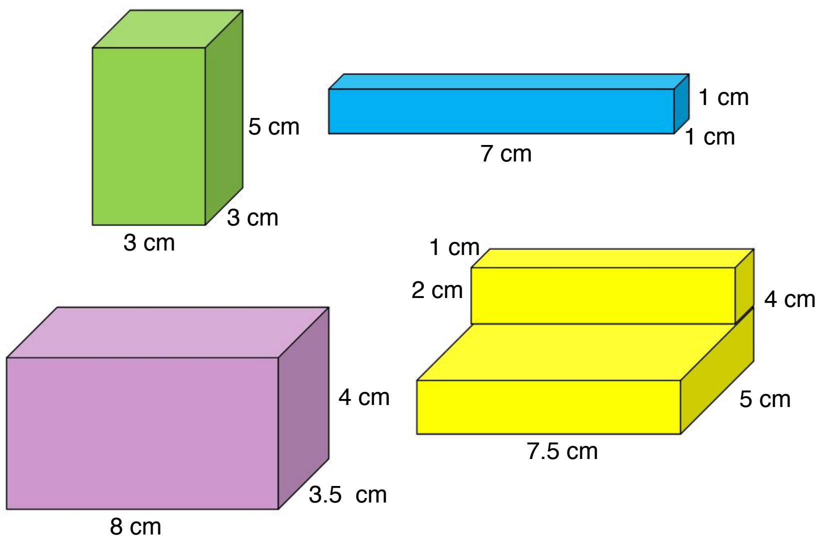


By combining these two steps (area of the bottom of the object and height of the object), we can find the volume of a regularly-shaped object. The area of the bottom (length x width) times the height of the object or L x W x H equals the volume of the object.



In this example we used centimeters as our units of length. We have the length in cm x width in cm and the height in cm. Multiplying these together we get cm^3 or cubic centimeters. So, our volume measurement is in cubic units. An object measured in inches would have a volume in cubic inches; in feet, the volume would be in cubic feet. Something very large might have its volume measured in cubic miles. The key here is that volume is measured in cubic units.

Let's practice this concept now. Look at the regularly-shaped objects below. Find the volume of each object. Remember, first find the area of the bottom of each object and then multiply that result by the height (number of layers of cubes) of the object.



Answers:

Green shape: 45 cubic cm or 45 cm^3

Blue shape: 7 cubic cm or 7 cm^3

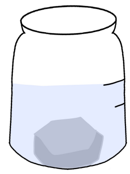
Purple shape: 112 cubic cm or 112 cm^3

Yellow shape: Bottom portion = 75 cubic cm; top portion = 15 cubic cm; total volume = 90 cubic cm or 90 cm^3

Here are your design challenges for Lesson 3:

Challenge 1: Create a box which has a volume (when measuring outside dimensions) of 500 cubic centimeters. The box must have solid sides. Your box must be able to survive the crash test of 2 meters from a hard floor.

Challenge 2: Create a box with an **internal** volume of exactly 750 cubic centimeters. The box must have solid sides. Your box must include a lid which has functional hinges (a device which allows the lid to be affixed to the remainder of the box, yet allow the lid to open and close). The lid must also have a locking mechanism. Your box must be able to survive a crash test of 3 meters from point of release to the floor.



Lesson 4: Finding the Volume of Irregularly-shaped Objects

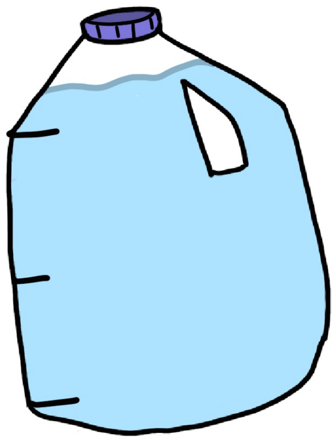
In Lesson 3, you were introduced to the measurement of volume. We said that volume was the amount of space something took up and it was a three-dimensional measurement. In Lesson 3 we learned how to find the volume of a regularly-shaped object. This was a derived measurement found by multiplying the length, width and height measurements of an object. The resulting measurement was in cubic units. Let's look now at how we might go about finding the volume of an irregularly-shaped object (one that doesn't have flat sides).

Finding the volume of an irrengularly-shaped object is slightly more complicated than finding the volume of a regularly-shaped object.

Think about a rock. The surfaces of most rocks are not flat, so it's difficult to determine how many square units are present in the base of the object. And because the height of the rock can't be accurately measured, it's difficult to compute the number of cubic units that can "fit" inside the rock. Because of these irregular surfaces, we must use a different approach to find the volume of the rock.

The method we'll describe here is known as finding volume by displacement. This method will also allow us to explore the method we use to find the volume of liquids. Because finding the volume of an irregularly-shaped object requires understanding how to find the volume of a liquid, let's begin there.

Like length, the unit used to measure the volume of a liquid is a base unit. Recall that with length, our base unit using the SI system was the meter. With the volume of a liquid, our base unit using the SI system is the liter.



English units for the volume of a liquid can be in gallons, quarts or ounces. Drinks, like pop, come in bottles measured in the SI units which are liters. A commonly used part of a liter often used in science and medicine is the milliliter which is one one-thousandth of a liter.

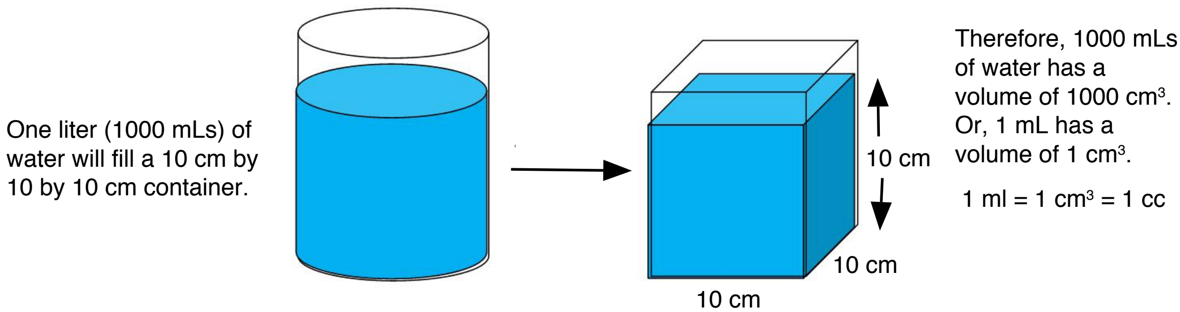
We can use the same set of prefixes as we did with length to designate multiples of liters or parts of liters. The most commonly used measure of volumes of liquids is the milliliter. Recall that the prefix milli- means one-thousandth, therefore a milliliter is equal to one-thousandth of a liter. So, if we took one liter of a liquid and divided it into 1000 equal parts, each part would represent 1 milliliter or 1 mL.

Metric Prefix Table

Prefix	Symbol	Multiplier	Exponential
tera	T	1,000,000,000,000	10^{12}
giga	G	1,000,000,000	10^{9}
mega	M	1,000,000	10^{6}
kilo	k	1,000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
UNIT	NONE	1	10^{0}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	m	0.000001	10^{-6}
nano	n	0.000000001	10^{-9}
pico	p	0.000000000001	10^{-12}

Example of how to read the table: If a unit has the prefix giga (denoted by adding G before the unit symbol), that unit is 1,000,000,000 (or 10^{9}) times bigger than the original unit. For example, a gigawatt (GW) is 10^{9} times as big as a watt.

Interestingly, if we took one liter (1000 ml) of water and placed it into a container with flat sides and found its volume using a length times width times height calculation, we would find that one liter of water has a volume of 1000 cubic centimeters. Based on this relationship, we can also say that one thousand milliliters has a volume of one thousand cubic centimeters and, therefore, one milliliter has the same volume as one cubic centimeter (1 mL = 1 cm3 or 1 cc).



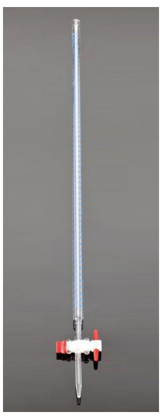
Let's go back to our discussion of finding the volume of a liquid. A measuring instrument frequently used to measure volumes of liquids is the graduated cylinder. The term graduated refers to having marks or graduations and these devices are cylindrical in shape, hence the name graduated cylinder. Look at the photo below of a graduated cylinder.

Graduated cylinders are very useful when measuring precise volumes of liquids.

Note that each mark or graduation on the cylinder represents ten milliliters of liquid. By pouring a liquid into the top opening of the cylinder, we can measure the volume of the liquid in milliliters. More precise graduated cylinders that can measure to single milliliters can be used when one needs to be more precise in measuring volumes.

Photos this page courtesy Southern Labware.

A case where this is especially important is in medicine where it is extremely important to measure correct dosages of medications. When dosages need to be carefully measured, syringes are used. Traditionally, ccs (or cubic centimeters) are used to measure liquid medications and you will commonly see dosage requirements in ccs. Knowing that a cc is the same as a milliliter can be handy with preparing medications. Other instruments commonly used in labs to measure liquids are the micropipet (my-crow pie-pet) and the buret (byoo-ret).

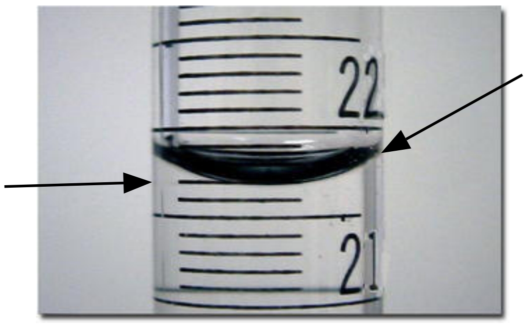


The buret (left) is a long, glass tube with a special valve at the bottom called a stopcock (orange and white in this model). Along the tube are increments of milliliters and by careful manipulation of the stopcock, a person can dispense very precise amounts of liquids.

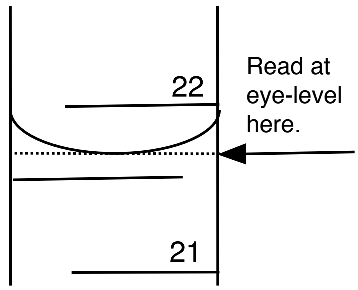
The micropipette (right) can transfer even tinier amounts of liquids in a very precise manner. The operator depresses the thumb button on top of the handle and lowers the tip into the desired liquid. By releasing the thumb button, the exact volume of liquid is drawn up into the tip of the micropipette. Depressing the button again, allows the liquid to be dispensed in the desired location. Tiny, exact portions of milliliters of liquids can be measured using these instruments.

Let's practice making some liquid volume measurements by examining some diagrams of graduated cylinders with varying volumes of liquid. Take a look at the first graduated cylinder.

Note that the upper surface of the liquid is not flat, but instead, curved. The curvature is due to the fact that liquids experience an attractive force to the side of the cylinder which results in a curved surface. This attractive force is known as adhesion. This curved shape is known as the meniscus.



The meniscus is the curved surface on the surface of the water in this graduated cylinder. The water level should be read at the bottom of the curve. In this case, the water level is 21.7 mL.



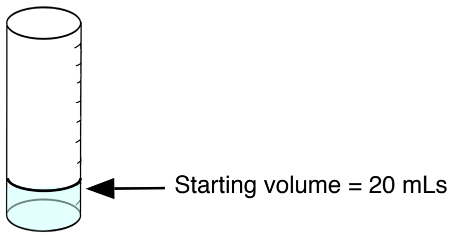
Because of this curve, it may be slightly confusing to know exactly where to measure the volume of liquid. The accepted technique is to use the "bottom" of the meniscus as the point to make your measurement. Notice in the diagram how the "bottom" of the meniscus is used to measure the volume of a liquid inside a graduated cylinder.

Now that we know how to measure the volume of a liquid, let's go back to our discussion of measuring the volume of an irregularly-shaped object. We said earlier that we can't utilize our length x width x height method because the surfaces of an irregularly-shaped object are not flat. We have parts of the object that protrude or are sunken on the surface. So, how can we find the volume?

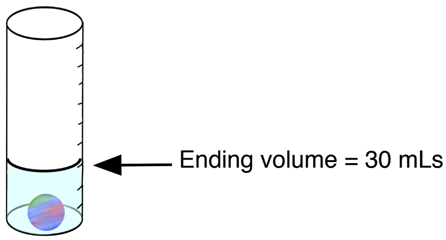
We'll find the volume by using the displacement method. The term displacement means that something is moved "out of the way" due to the action of another object or substance. In this case we'll allow our irregularly-shaped object (our rock) to displace another substance. A readily available substance we can use is water.

Now before we find the volume of our rock, let's look at a simpler example. Let's pretend we need to find the volume of a marble and we will do so using the displacement method.

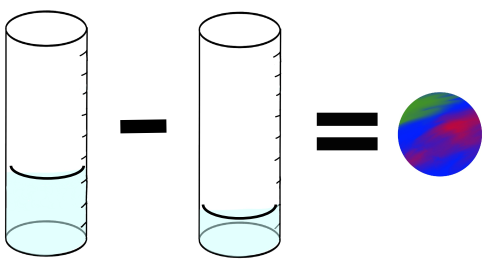
We'll begin by partially filling our graduated cylinder with water. We'll call this amount of water our "starting volume." As you can see in the photo below, our starting volume will be 20 mL.



Next, we'll drop in our marble.



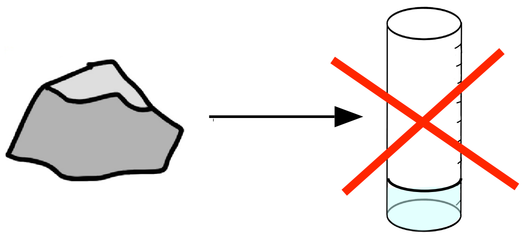
What happens to the water level? It goes up, right? Why does that happen? Obviously, the marble, which has a volume of its own, pushes the water out of the way. It displaces the water. How much water was displaced? The amount (volume) of water that gets displaced is equal to the volume of the object that did the displacing. In other words, the volume *change* of the water equals the volume of marble.



30 mLs - 20 mLs = 10 mLs

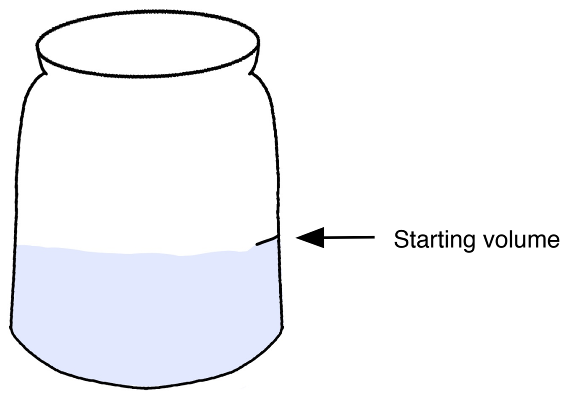
By subtracting the starting volume from the ending volume, we can find the amount of water which was displaced. In our example our ending volume was 30 mL. Therefore the volume of water that was displaced is 30 mLs - 20 mLs = 10 mLs. This means the volume of our marble is 10 mLs.

But what about an irregularly-shaped object that won't fit down inside a graduated cylinder?

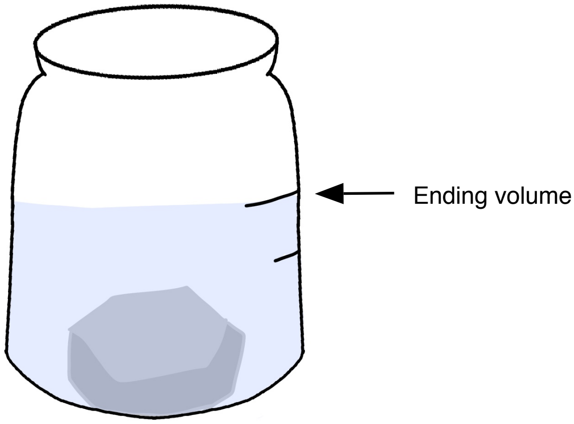


Think back to our earlier question about finding the volume of a rock. What if our rock won't fit down inside a graduated cylinder? Can you think of how you might go about measuring its volume? Because the rock won't fit into our graduated cylinder, we'll use another container to hold our "starting" volume of water. We'll then add the rock to the water in that container and determine the change in volume.

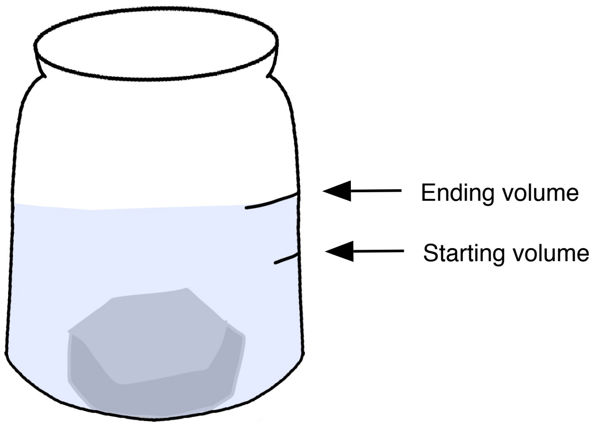
Here you can see that we've taken a jar and partially filled it with water. We'll mark the side of the jar at the level of the water.



In this diagram you can see that we've added our rock to the container. Note how the water was indeed displaced as we expected. As we discussed earlier, this change in volume is equal to the volume of our rock. We'll place a second mark now at this "new" level. It's the difference between our two marks that we'll need to find. This mark is our "ending" mark.

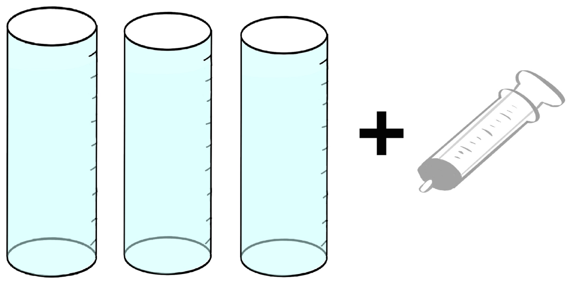


We'll find this difference by first removing our rock and all of the water from the jar. We'll refill the jar to our first mark (the starting mark) and then by adding known amounts of water, measured using our graduated cylinder, we can find how much water it takes to get to the "ending" mark. The difference in volume between the starting and ending volumes will equal the volume of the rock.



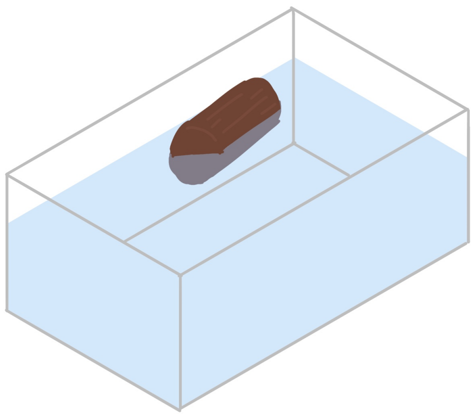
To help us not accidentally overfill water past the ending mark, we'll use a syringe to slowly come up to the ending mark. Recall that most syringes measure in ccs which are the same as milliliters. While filling, it's important to keep track of how many times you fill the graduated cylinder or syringe. When you've filled the jar to the ending mark, the total number of milliliters you used is equal to the volume of the rock (or unknown object).

In our example here, you can see that we filled our graduated cylinder three times, each cylinder holding 50 mLs for a total of 150 mLs. We then "topped it off" by adding 8 ccs (mLs) with the syringe. This gave us a total of 158 mLs displacement which means the rock has a volume of 158 mLs. How many cubic centimeters would this be equal to? If you said, 158 ccs, you're correct!



50mLs + 50 mLs + 50 mLs + 8 mLs = 158 mLs

Note that finding the volume of irregularly-shaped objects by displacement works best for objects that sink when placed into water. What about something like a piece of wood that tends to float when placed in water?



Finding the volume of an irregularly-shaped object which floats when placed into water can be challenging!

Can you think of any ideas on how to accomplish this? Could you possibly push it down beneath the surface of the water or maybe place a heavy object on top of it and force it down beneath the surface? Will you need to find the volume of heavy object, too? What if you tied a heavy object to your unknown object and allowed it to pull the object down below the water level? Would you have to take into account the volume of the rope or string you used for tying, too? With some creative thinking, you should be able to find the volume of just about any solid object using the displacement method.

Before we leave this lesson on volume, let's look at the units used for volume in the English system. You are likely familiar with gallons, quarts and pints. A quart is one-fourth of a gallon while a pint is one-half of a quart. A pint is made of two cups. Cups can be divided into eight ounces. Two tablespoons make an ounce and three teaspoons make a tablespoon. As you can see, while Americans continue to use the English system, the simplicity of the metric system for measuring volume is appealing.

1 gallon = 4 quarts
1 quart = 2 pints
1 pint = 2 cups
1 cup = 8 ounces
1 ounce = 2 Tablespoons
1 Tablespoon = 3 teaspoons

Lab 1: In this lab you'll practice finding the volume of four different irregularly-shaped objects.

Materials to gather: 4 irregularly-shaped objects, jar or other container which can hold water, measuring instrument such as a graduated cylinder, syringe or pipette. A soda straw can work, too,when marked at specific increments.

Procedure: Find the volume of each object according to the procedure presented in your lesson. Record your results and then have your mom, dad or teacher check your accuracy in making these measurements.

Challenge 1: In this challenge you will pretend to be a company which packages chicken eggs. Because packaging materials are relatively expensive for your company, you'll want to use the minimum amount of materials, yet have the egg fully enclosed on all surfaces. Choose one chicken egg and build a container that will fully enclose the egg yet only provide a maximum of clearance of 2 mm on any surface between the egg and the wall of the container. In other words, when the egg is placed into the container, you should see no more than 2mm of space between the surface of the egg and the interior surface of the box. The box should have a lid, working hinges and a locking mechanism. You may boil your egg first if you feel like it would be easier to handle as you construct and then test your box. Hint: the interior surface of the box need not be the box itself, but another "surface".