Lesson 6: Units and Unit Conversions

Introduction

This document is Lesson 6 of the SEAChem2020 open source chemistry curriculum program for secular homeschoolers. This version was current as of 8/30/2017. To if there is a more current version of this document, visit www.SEAChem2020.org.

Table of Contents:

How to use this material:

During the course of this lesson, your child should:

- Read the material in the text and rewrite it in their own words.
- Complete the practice sheet, then write their own, complete with answer key.
- Complete the lab activity, then write their own, complete with suggestions on how to best perform the lab.
- Take the assessment to ensure they understand the material, then write their own, along with solutions.

These steps should be followed by a debrief, in which you and your child will discuss the lesson. Please send us your suggestions, as well as any materials your child writes (text, practice, lab, assessment) so that we may incorporate it into the curriculum.[1]

We welcome any help you are willing to provide in supporting this project. Even if you're not a chemist or a professional educator, you can help in the following ways:

- **Let us know about minor fixes**. If you find anything from a factual to a stylistic error, or even a typo, let us know by using this form.
- **Let us know if you find big problems**. Does something need rewriting? Let us know by contacting us using this form.
- **Give us your resources**. If you've done one of these lessons and have put something cool together, email us at misterguch@chemfiesta.com so we can include it!
- **Volunteer**. Do you want to edit this curriculum? Do you have things to add? Would you like to write some of these lessons? Let us know!
- **Publicity**. Tell your friends about these resources. When the community grows, the project keeps growing!

Thank you for using this resource, and please consider helping out!

1 *Any submitted material added to the curriculum will be licensed under the same Creative Commons license as the rest of this material and will be free for others to use and adapt. Please make sure your name is included somewhere on the submitted resource(s) if you wish to receive credit for your work. All submitted resources may be edited for accuracy, formatting, and style.*

Chapter 6: Units and Unit Conversions

How much do you weigh? The average weight of teenagers in the United States is around 140, though there's a lot of normal variation in there as well.

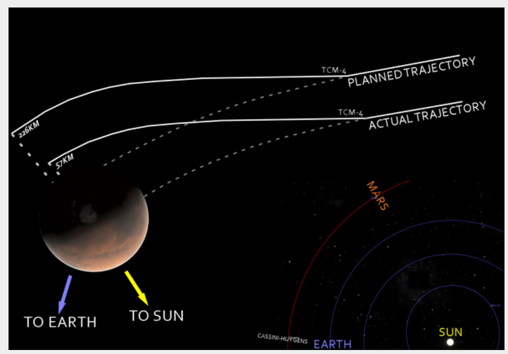
However, if you were a teenager from another part of the world, saying that you and your friends weighed about 140 would be shocking. They might understand why one of you weighed so much, but for everybody you know to weigh 140 is puzzling. And to hear that your *thin* friend weighed 90 would be equally shocking. Why are Americans so fat?

It turns out that hearing this is nothing more than a misunderstanding. If you were to say that you weigh 140, you'd mean that you weigh 140 *pounds*. On the other hand, foreign teenagers would assume that you meant *kilograms*, and 140 kilograms is equal to 310 pounds. Now you can understand how surprising it would be to a foreign friend to hear that you weighed 140!

Whenever we tell somebody numerical data, we need to make sure that we tell them the units of these numbers to ensure that there are no misunderstandings of this sort.

Bad Units

In 1998, NASA's Mars Climate Orbiter was launched to study the Martian atmosphere and climate. Unfortunately, this satellite was destroyed when data for the thrusters was sent by Lockheed Martin ground stations in U.S. customary units when the NASA instrument on the satellite was expecting SI units. As a result, the satellite attempted to enter orbit at too low an altitude, causing it to be destroyed.



The Mars Climate Orbiter was destroyed due to unit-based misunderstandings.

SI Units

The standard units used by scientists are SI units.[2,3] These units can be used to measure just about anything and are the basis for nearly all scientific measurements.[4] SI units can be broken into two categories: base units and derived units.

Base units are the fundamental units that are used to make measurements. There are seven SI base units, of which five will be useful to us in this course:[5]

2 *SI stands for* Système international d'unités*, which is French for "international system of units."*
3 *"SI" is often used synonymously with "metric", when really, SI units are an expanded form of the metric system.*
4 *There are exceptions, though these are disappearing. For example, engineering and meteorology both make use of non-SI units.*
5 *Ampere and candela will not be seen again after this section.*

Base unit (abbreviation)	What it measures
ampere (A)	electrical current
candela (cd)	brightness of light
kelvin (K)	temperature
kilogram (kg)	mass
meter / metre (m)	distance
mole (mol)[6]	amount of substance
second (s)	time

These seven units, while handy, aren't useful for measuring everything. Because of this, we need **derived units**, which are units that are either modifications of combinations of base units that allow us to measure everything else.

This can be done in two ways:

- Prefixes: In order to modify a base unit to be a little easier to work with, we can add a prefix in front of the unit to change it. A good example of this is the "kilometer", which is equal to 1,000 meters.
- Combinations of units: There are no units of velocity in the SI system. However, if we combine the units for distance (m) and time (sec), we get units of "m/s" for velocity. Other examples include liters (1 dm^3) and joules ($kg \cdot m^2 \cdot s^{-2}$).

Metric prefixes

Metric prefixes are symbols or letters that are added to the front of units to either increase or decrease their size. There are many prefixes out there, but only a few that we use on a regular basis:

Prefix	Meaning	Frequently seen in
nano (n)	one-billionth / 10^{-9} / 0.000000001	nanometers (nm)
micro (μ)	one-millionth / 10^{-6} / 0.000001	micrometers (μm, more frequently called microns)
milli (m)	one-thousandth / 10^{-3} / 0.001	millimeters (mm), milliliters (mL)
centi (c)	one-hundredth / 10^{-2} / 0.01	centimeters (cm)
deci (d)	one-tenth / 10^{-1} / 0.1	deciliters (dL), decimeters (dm)
kilo (k)	one thousand / 10^3 / 1,000	kilometers (km)

6 *You may wonder why anybody would abbreviate "mole" as "mol" when there's only one letter difference. It's said (though it's hard to confirm) that this was first done by German chemists, who came up with the term by abbreviating the word "molekül" (molecule) as "mol" because in German the sound "mol" sounds more like "molecule" than "mole."*

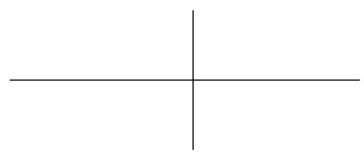
Each of these prefixes literally means whatever number it stands for. For example, if I were to refer to “50 kilograms”, this literally means “50 x 1,000” grams, or 50,000 g. Likewise, “45 centimeters” means “45 x 0.01” meters, or 0.45 m.

There are various tricks that you can use to convert from meters to kilometers, or grams to mg. However, it has been my experience that it's very easy to make mistakes using these methods, making them fairly unreliable in practice. As a result, we will learn how to convert between them using a somewhat more elaborate method. This method is, admittedly, more complete than is necessary for converting units, but will come in extremely handy later in this course when more involved calculations are required. This method is called the “**T-chart method**”.[7]

To understand how the T-chart method works, let's use the following example: Convert 5.3 centimeters to meters.[8]

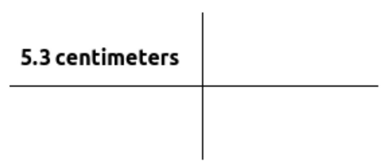
Step 1: Draw a t

It's as simple as this:



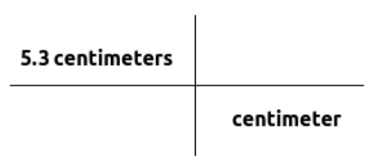
Step 2: Write whatever you're trying to convert in the top left part of the t.

In this case, we're trying to convert “5.3 centimeters” to meters, so let's write that in the top left.



Step 3: Transfer only the units of what you already wrote to the bottom right of the t.

Because “5.3 centimeters” is on the top left, we transfer only “centimeters” to the bottom right.



7 *At least, in the form shown here. This method is more-commonly known as the “factor label method”, and is functionally identical to it. However, the presentation of the “T-chart method” as shown here is, in my experience, easier to understand.*

8 *Many readers will undoubtedly figure out that this is equal to 0.053 m without needing to use this method. That's precisely why I'm using this example: So you can see how it works in something you already understand. Most of the problems you'll be solving will not be so intuitive!*

Step 4: Write the units of what you're trying to convert to on the top right.

We're trying to convert to meters, so let's write that on the top right.

5.3 centimeters	**meters**
	centimeter

Step 5: Put numbers in front of each unit on the right.

How do we know what to put? It's as simple as this:

- Write a "1" in front of any unit with a metric prefix (milli, centi, kilo, etc.)
- Write whatever that prefix means in front of the other thing

In our case, we're converting centimeters to meters, so let's write "1" in front of centimeters ("centi-" is a prefix, after all), and "0.01" in front of meters (because "centi-" is equal to 0.01).[9]

5.3 centimeters	**0.01 meters**
	1 centimeter

Step 6: Multiply the numbers on the top of the t together and divide by the numbers on the bottom of the line.

Here, we multiply "5.3 cm" by "0.01 m", and then divide by "1 cm". This gives us an answer of 0.053 m.

5.3 centimeters	**0.01 meters**	**= 0.053 meters**
	1 centimeter	

Did we do it right?

When you're done with a unit conversion, you may be worried that your answer is incorrect. Use the following suggestions to help you figure out whether you've got the right answer:

- ***Does it pass the common sense test (part 1)?*** *Imagine you've done a calculation and found that something is 7,000,000,000,000 meters long. Quick question: When's the last time you counted seven trillion of anything? Unless you have a good reason to think that something is ridiculously big or small, check your work.*
- ***Does it pass the common sense test (part 2)?*** *If you've done a calculation that says a dollar bill is 9.5 meters long, does the answer seem right? If not, check your work!*
- ***Did you follow the steps?*** *C'mon – did you take a shortcut somewhere along the line? If you did, you might not have done it right.*

If none of these are the case, it doesn't necessarily mean that you've done your calculation correctly. However, it can help you to avoid making obvious mistakes.

9 *You may be wondering what we put in the bottom left of the t. Nothing! If you feel the need to add something, I suggest a smiley face.*

Using T-charts for more elaborate unit conversions

It turns out that this T-chart method can be used for more than just converting between centimeters and meters. Let's see two more examples: One where we convert between two different metric prefixes and one where we convert between customary units and SI units.

Converting between two metric prefixes:

Sample problem: Convert 5.3 cm to mm.

In this case, we're converting from one prefix ("centi-") to another ("milli-"). Unlike the first problem, where we converted 5.3 mm to m in one calculation, we now have to make the conversion in two calculations. The first will convert 5.3 cm to m, and then the second will convert this to mm. Since we've already done the first part of this calculation, we'll start with what we had:

5.3 centimeters	0.01 meters
	1 centimeter

And from here, we'll just go back and do the steps again to convert from meters to millimeters.

Step 1: Let's extend the t for another step:

5.3 centimeters	0.01 meters	
	1 centimeter	

Step 2: Not applicable – the numbers on the left are already set up.

Step 3: Put the unit from the top left corner into the empty bottom right. In this case, we're moving "meters".

5.3 centimeters	0.01 meters	
	1 centimeter	meters

Step 4: Put the unit of what we want to find in the top right corner. In this case, it will be "millimeters."

5.3 centimeters	0.01 meters	millimeter
	1 centimeter	meters

Step 5: Add conversion factors. Remember that we always put a “1” in front of the prefix (millimeters, in this case) and whatever the prefix means (milli- means “0.001”) in front of the other unit:

5.3 centimeters	0.01 meters	1 millimeter
	1 centimeter	0.001 meters

Step 6: Do the calculation. When we multiply the numbers on the top by the numbers on the bottom (5.3 cm x 0.01 m x 1 mm) and divide by the numbers on the bottom (1 cm x 0.001 m), we get an answer of 53 mm.

5.3 centimeters	0.01 meters	1 millimeter	= 53 millimeters
	1 centimeter	0.001 meters	

Though I know that many of you could probably have done the conversion in their head, I again want to strongly recommend that you learn this method of doing calculations. It may seem like overkill, but it's foolproof and will be used repeatedly in future lessons. Time to bite the bullet and get it out of the way.

Converting from Customary Units to SI units

Because many users of this lesson are far more familiar with Customary Units than SI units, it seems reasonable to discuss the use of the t-chart method in making these conversions. The basic idea behind the calculation is the same, with the only difference being that the conversion factor between units has to be given to you in the problem.

Example: Convert 67.6 centimeters to inches. There are 2.54 cm in 1 in.

Step 1: Make a t.

Step 2: Put whatever you're given in the top left.

67.6 cm	

Step 3: Put the units of what you were given in the bottom right.

67.6 cm	
	cm

Step 4: Put the units of what you're trying to find in the top right.

67.6 cm	inch
	cm

Step 5: Add the conversion factor. In this question, the conversion factor was given to you, so all you need to do is to write “2.54” in front of “cm” and “1” in front of “in.”

67.6 cm	1 inch
	2.54 cm

Step 6: Do the math by multiplying the numbers on the top and dividing by the numbers on the bottom. This gives an answer of 26.6 cm.[10]

67.6 cm	1 inch	= 26.6 cm
	2.54 cm	

As you can see, the calculation is almost exactly the same as it was for units within the metric system. It is this kind of flexibility that makes this method of performing calculations so useful.

Kelvin (K):

The SI unit for temperature is kelvin. To convert from degrees Celsius to kelvin, simply add 273 to the temperature in degrees Celsius. For example, if the temperature of an object is 35 °C, the temperature in Kelvin is 35 + 273 = 308 K. Note that the unit for kelvin is simply “kelvin”, with no “degrees” needed.[11]

William Thomson was elevated to the title of 1st Baron Kelvin of Largs in 1892 because of his scientific achievements and opposition to Irish home rule.[12]

The Main Ideas in This Lesson

- The sciences generally use SI units.
- Base units are the basis for all SI measurements. Derived units are units that are made either by modifying these units with prefixes or combining these units.
- The T-chart method of calculations can be used to convert between units with different prefixes or between SI and customary units

10 *Though your calculator probably read “26.61 cm”, remember that we need to use significant figures when doing calculations.*
11 *To be more precise, the actual conversion from degrees Celsius to kelvin is 273.15, though it's rarely necessary to be concerned with this level of precision.*
12 *The home rule movement advocated for Ireland to have self-government while remaining within the United Kingdom. This ceased being an issue in 1922, when the Irish Free State was established.*

Lesson 6: Glossary

base units: the fundamental units used to make measurements using SI units. These include the ampere (A), the candela (cd), the kelvin (K), the kilogram (kg), the meter (m), the mole (mol), and the second (s).

centi (c): prefix meaning one-hundredth.

customary units: Non-SI units that are used in different parts of the world. The most commonly seen are the Imperial units used in the U.K. and U.S. customary units (U.S.)

deci (d): prefix meaning one-tenth.

derived units: Units that have been modified from base units either by adding a prefix or by combining base units.

kilo (k): prefix meaning 1,000.

micro (μ): prefix meaning one-millionth.

milli (m): prefix meaning one-thousandth

SI units: The international system of units most commonly-used in the sciences. Often referred to as the metric system, though the two terms are technically not synonymous.

T-chart method: The method we learned in this lesson to perform unit conversions. We will be seeing it frequently in future lessons.

Lesson 6: Practice Sheet

1) Convert 36 µg to grams.

2) Convert 7.5 km to meters.

3) Convert 8.8 centimeters to microns.

4) Convert 32.6 inches to centimeters. There are 2.54 centimeters in 1 inch.

5) Convert 51 degrees Celsius to kelvin:

6) What is the difference between a base unit and a derived unit? Give examples of each.

7) What is the metric base unit for amount of substance?

8) The metric prefix for 10^{-24} is “yocto-”. Given that this unit has a name, why do you believe it's so very rarely used to take measurements?

Lesson 5: Practice Sheet - Answers

1) Convert 36 µg to grams.

36 µg	10^{-6} g	= 3.6×10^{-5} g
	1 µg	

2) Convert 7.5 km to meters.

7.5 km	1000 m	= 7500 m
	1 km	

3) Convert 8.8 centimeters to microns.

8.8 cm	0.01 m	1 µm	= 88000 µm
	1 cm	10^{-6}m	

4) Convert 32.6 inches to centimeters. There are 2.54 centimeters in 1 inch.

32.6 in	2.54 cm	= 82.8 cm
	1 in	

5) Convert 51 degrees Celsius to kelvin:
51 °C + 273 = 324 K

6) What is the difference between a base unit and a derived unit? Give examples of each.
A base unit is a fundamental unit that's used to measure something. There are seven base units (ampere, candela, kelvin, kilogram, meter, mole, and second). All other units are derived units that are expressed in terms of these other units, either by adding prefixes or combining base units. Examples of derived units include centimeters, milligrams, and liters.

7) What is the metric base unit for amount of substance?
moles (mol)

8) The metric prefix for 10^{-24} is "yocto-". Given that this unit has a name, why do you believe it's so very rarely used to take measurements?
Yocto isn't very commonly used because there are very few things that are this small. For example, 1 yg is less than the weight of a proton (which weighs about 1.67 yg).

<u>Lesson 6 Lab Activity</u>

Measurements and Unit Conversions - Answers

Introductory note: This lab is intended to go along with Lesson 6, which covers SI base and derived units, as well as unit conversions. As such, it is more important that your child understands how to perform unit conversions than it is that he/she get the “right” answer.

Equipment needed: Tape measure (ideal), yard stick (less ideal), or ruler (least ideal).

Safety: The only foreseeable safety hazard may come from falls when your child finds the height of his/her room.

Room destruction factor: It seems unlikely that this could damage your home.

What can go wrong: The unit conversion calculations are may be problematic and significant figures are the most likely source of error.

Lab answers:

Procedure: Each of the measurements should be made in inches. The precision to which these measurements should be given is to the hundredths of an inch.

Calculations:

1) The volume of the room will be equal to the product of the three measurements in the procedure section. The number of significant figures of the answer should be correct, based on the measurements. As an example, the room in which this lab is being written has a length of 134.50 inches, a width of 96.14 inches, and a height of 83.88 inches. Multiplying them together give an answer of 1,084,638.02 in^3, which rounds to 1,080,000 in^3 or 1.08 x 106 in^3.

2) To convert each of the measurements to centimeters, multiply by 2.54. In my case, this works out to:
   - 134.50 inches x 2.54 cm/in = 342 cm.
   - 96.14 inches x 2.54 cm/in = 244 cm.
   - 83.88 inches x 2.54 cm/in = 213 cm.

   When these are multiplied together, we get an answer of 17,774,424 cm^3, which rounds to 17,800,000 cm^3.

3) To determine the volume of the room in liters, we would divide the number of cubic centimeters from #2 by 1,000. Using the information I've collected, this would be equivalent to a volume of 17,800 L.

4) Divide #3 by two to get the number of 2 L bottles. In this case, it's 8.90×10^3 bottles.

5) The author of this lab drinks soda at a rate of approximately 1.5 bottles per day. At this rate it would take 5930 days or 16.2 years to finish them all.

6) To determine this answer, divide the answer from #2 by 236.6 cm3. For me, this gives an answer of 75,200 cups.

Lesson 6 Lab Activity:
Measurements and Unit Conversions

The goal of this lab is simple: Find the volume of your bedroom in various sets of units. You need only measure it once – the rest will be done via unit conversion. A reminder: Don't forget to use significant figures in your answer!

Procedure:

1) Using a tape measure or other ruler, find the length of your room in inches: __________

2) With the same measuring tool, determine the width of your room in inches: __________

3) Again with the same tool, determine the height of your room in inches: __________

Calculations:

1) Using your measurements, determine the volume of your room in cubic inches (in^3):

2) Convert your measurements to centimeters, and then determine the volume of your room in cubic centimeters (cm^3):

3) Given your answer in question 2, determine the volume of your room in liters. There are 1,000 cubic centimeters in a liter.

4) How many 2 liter bottles of soda would fit inside of your bedroom?

5) Given your current consumption of soda, how long would it take you to drink your room's volume in soda?

6) There are 236.6 cubic centimeters in one cup. Given this information, how many cups of soda would fit in your room?

Lesson 6: Assessment

1) Convert 8.9 milligrams to grams.

2) Convert 636 meters to kilometers.

3) Convert 86.8 deciliters to milliliters.

4) Convert 0.981 gallons to liters. There are 3.79 liters in 1 gallon.

5) Convert 563 K to degrees Celsius.

6) Explain why prefixes are useful when working with SI units.

Lesson 6: Assessment – Answers

1) Convert 8.9 milligrams to grams.

8.9 mg	0.001 g	= 0.0089 g
	1 mg	

2) Convert 636 meters to kilometers.

636 m	1 km	= 0.836 km
	1000 m	

3) Convert 86.8 deciliters to milliliters.

86.8 dL	0.1 L	1 mL	= 8680 mL
	1 dL	0.001 L	

4) Convert 0.981 gallons to liters. There are 3.79 liters in 1 gallon.

9.81 gal	3.79 L	= 37.2 L (remember sig figs!)
	1 gal	

5) Convert 563 K to degrees Celsius.
563 K – 273 = 290. °C
Note here that since significant figures rounds to the nearest whole degree, the decimal place must be shown to indicate that the zero is significant.

6) Explain why prefixes are useful when working with SI units.
Prefixes allow us to turn the base units into more manageable derived units. For example, let's say that we have a very small amount of chemical to work with. Though it's not incorrect to say that we want to work with “0.0000075 L” of the chemical, it's much easier to visualize “7.5 μL”.

Lesson 6: References for further study

A comprehensive history of the metric system:
http://www.us-metric.org/origin-of-the-metric-system/

The "Big-K" is the prototype kilogram. Read about it here:
http://news.nationalgeographic.com/2015/07/150715-kilogram-avogadro-chemistry-science-history-metric-units-mole-atom-mass/

How the meter was invented:
http://www.npr.org/2014/06/23/324738251/how-did-the-meter-get-its-length

An entertaining discussion of metric prefixes:
http://www.businessballs.com/metricprefixes.htm

When is "kilo" not exactly 1000?
https://physics.nist.gov/cuu/Units/binary.html

Some decidedly un-metric units, for fun and entertainment:
http://www.neatorama.com/2009/01/30/fun-and-unusual-units-of-measurements/

Six cases where bad unit conversions led to disaster:
http://mentalfloss.com/article/25845/quick-6-six-unit-conversion-disasters