# Science-1A Lab: Week 1, Wednesday, August 11, 2021

The metric system (formally known  the International System of Units, abbreviated SI) is based on measurement units like the meter for length, kilogram for mass, second for time, joule for energy, newton for force and weight, etc.  It is used exclusively in science and medicine, and by ordinary people in nearly all countries of the world except the United States.  The SI system is much easier to use and remember, but when the United States was about to switch to the metric system in 1982, President Reagan did not allow the change.  See *https://en.wikipedia.org/wiki/International_System_of_Units*
for a full discussion of the SI system.

In the United States, we are one of the last three countries in the world (along with Liberia and Myanmar) to still use a version of the old English System which the English no longer use.  The English system uses inches, feet, yards and miles for length, and a hodge-podge of other units described at *https://en.wikipedia.org/wiki/United_States_customary_units* .  I like to exclusively use the SI system in Science-1A and normally avoid even discussing conversions between our backward system and the nice, logical SI system.

In this note, I use scientific notation and unit conversions which are carefully explained in the following:
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/AlgebraRefresher.pdf*
(Video explanations of most of the sections of this handout may be viewed via the school Canvas system.)
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/ScientificNotation.pdf*
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/UsingUnits.pdf*
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/PracticeWithUnitPrefixes.pdf*
**It is very important to know how to use scientific notation and units in this course!**

## What we would do in the school lab

When meeting at the school, I can pass out meter sticks, metric micrometers, and a metric tape measure for everyone to use when measuring lengths.  I also pass out metric scales for weighing masses. Volumes are measured in cubic centimeters (= milliliters), cubic meters, and other closely-related units.

We then measure the length, width, and height of the lab tables and write down the result in meters, centimeters, millimeters, and fill out question 1 on the Measurement Worksheet on page 41 of the physics packet of notes and also on the yosemitefoothills.com website at
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/MeasurementWorksheet.pdf* .

When you measure your table and get, for example, that its top is 180 cm long, 120 cm wide, and 80 cm high, you might write that information as 180 cm x 120 cm x 80 cm.  The x's here are read as "by"; 180 cm long by 120 cm wide by 80 cm high.

If you were to consider that table a box and you wanted its volume, you would interpret those x's as multiplication signs: table volume = 180 cm multiplied by 120 cm multiplied by 80 cm = 1728000 $cm^3$.  Let me write this in a more careful mathematical manner using centered dots to signify multiplication and using parentheses to show how the numbers and their units are grouped:

$$V=(180\text{ cm})\cdot(120\text{ cm})\cdot(80\text{ cm}) = (180\cdot 120\cdot 80)\cdot(\text{cm}\cdot\text{cm}\cdot\text{cm}) = 1728000\text{ cm}^3$$

Possible values for the length, width, and height of a rectangular table are given in the table below which shows those sizes in meters, centimeters, and millimeters:

| | | | |
|---|---|---|---|
| length | 1.543 m | 154.3 cm | 1543 mm |
| width | 0.621 m | 62.1 cm | 621 mm |
| height | 0.762 m | 76.2 cm | 762 mm |

Examine these conversions and see how there are 100 cm in each meter and 10 mm in each cm.

Here, you can see that both the numbers and units get multiplied together. When the numbers are multiplied together we get 1728000, and when cm is multiplied by cm and again multiplied by cm, we end up with $\text{cm}^3$, cm cubed. So the volume is 1728000 $\text{cm}^3$.

Similarly, the area of the top of the desk is area = 180 cm multiplied by 120 cm = 21600 $\text{cm}^2$ , and we end up with

$$A=(180\ \text{cm})\cdot(120\ \text{cm}) = (180\cdot 120)\cdot(\text{cm}\cdot\text{cm}) = 21600\ \text{cm}^2$$

Because the length, width and height were measured in cm, the volume automatically became $\text{cm}^3$ and the area automatically became $\text{cm}^2$.

If the length, width, and height were measured in meters, the volume would be

$$V=(1.80\ \text{m})\cdot(1.20\ \text{m})\cdot(0.80\ \text{m}) = (1.80\cdot 1.20\cdot 0.80)\cdot(\text{m}\cdot\text{m}\cdot\text{m}) = 1.728\ \text{m}^3$$

and the area would be

$$A=(1.80\ \text{m})\cdot(1.20\ \text{m}) = (1.80\cdot 1.20)\cdot(\text{m}\cdot\text{m}) = 2.16\ \text{m}^2$$

If the length, width, and height were (ugg!!) measured in inches, the volume would be

$$V=(70.8661\ \text{in})\cdot(47.2441\ \text{in})\cdot(31.4961\ \text{in}) = (70.8661\cdot 47.2441\cdot 31.4961)\cdot(\text{in}\cdot\text{in}\cdot\text{in}) = 105449\ \text{in}^3$$

To convert this to $\text{cm}^3$, we need to multiply by $(2.54\ \text{cm/in})^3 = 16.3871\ \text{cm}^3/\text{in}^3$.

$$(105449\,\text{in}^3)\cdot(16.3871\,\text{cm}^3/\text{in}^3)=1728000\,\text{cm}^3$$

Here, the $\text{in}^3$ on the top cancels the $\text{in}^3$ on the bottom and we are left with $\text{cm}^3$ for the answer's units.

In this class, and in science in general, we don't mess with inches. We just measure in mm, cm, m, etc., and only need to adjust the powers of 10 to convert between the different sizes of units. Metric units make life much easier and less error prone.

Be careful, however, with time. For time, powers of 10 don't work if we talk about time in terms of minutes, hours, days, and years. If we just stick with seconds and use scientific notation for large or small numbers, our work is much easier.

We next measure the thickness of a sheet of paper and the diameter of a strand of hair using a micrometer (See *https://en.wikipedia.org/wiki/Micrometer* ). When using a micrometer, be sure that the locking lever is not in the locked position. Also, take care to used the "clicker" at the end of the micrometer drum to ensure an adeqate, but gentle, clamping action that gives a good reading without damaging the very delicate threaded innards of the micrometer. The clamping surfaces should be wiped to remove dirt and the zero reading checked. The zero point is not necessarily at zero, but can be used to correct the reading. If the zero point was at, for example, –0.02 mm and the paper reading was +0.09 mm, the paper thickness would be equal to 0.09 – (–0.02) = 0.11 mm. Carefully examine the marks on the barrel and play with the micrometer to appreciate how the marks should be interpreted. For example, open it until its opening is 1.00 cm according to a ruler and then see what its marks show. It is easy to misread a micrometer.

Another measuring instrument that has comparable resolution is a vernier caliber (See *https://en.wikipedia.org/wiki/Calipers#Vernier_caliper* ). It is a bit less accurate and harder to use, but can measure depth and inside diameters which a normal micrometer cannot measure.

A typical person's hair might be 0.06 mm in diameter. The measured number needs to be recorded on the worksheet along with its conversions to m, cm, and μm. For that 0.06 mm diameter hair, the conversions would be

$$0.06\,\mathrm{mm}=6.0\times10^{-2}\,\mathrm{mm}=(6.0\times10^{-2}\,\mathrm{mm})\cdot(\frac{1.0\times10^{-3}\,\mathrm{m}}{1.0\,\mathrm{mm}})=6.0\times10^{-5}\,\mathrm{m}=0.000060\,\mathrm{m}\quad,$$

$$0.06\,\mathrm{mm}=6.0\times10^{-2}\,\mathrm{mm}=(6.0\times10^{-2}\,\mathrm{mm})\cdot\left(\frac{1.0\times10^{-3}\,\mathrm{m}}{1.0\,\mathrm{mm}}\right)\cdot\left(\frac{1.0\times10^{6}\,\mu\mathrm{m}}{1.0\,\mathrm{m}}\right)=6.0\times10^{1}\,\mu\mathrm{m}=60\,\mu\mathrm{m}\quad,$$

and $$0.06\,\mathrm{mm}=6.0\times10^{-2}\,\mathrm{mm}=(6.0\times10^{-2}\,\mathrm{mm})\cdot\left(\frac{1.0\times10^{-3}\,\mathrm{m}}{1.0\,\mathrm{mm}}\right)\cdot\left(\frac{1.0\times10^{2}\,\mathrm{cm}}{1.0\,\mathrm{m}}\right)=6.0\times10^{-3}\,\mathrm{cm}=0.0060\,\mathrm{cm}$$

Next, we would measure the room interior size and obtain something like

length: 9.82 m        width: 9.51 m        height: 2.83 m

When these are multiplied together, we get the room volume in cubic meters:

$$V=(9.82\,\mathrm{m})\cdot(9.51\,\mathrm{m})\cdot(2.83\,\mathrm{m})=264.3\,\mathrm{m}^3$$

We would then pass out 5 marbles to each group. The marbles are not perfectly round, but a measurement is made of each and their average diameter is calculated with a standard deviation.

I wrote a calculator application which is at *https://yosemitefoothills.com/Calculator* . The top choice on that page is what we use for simple mean and standard deviation calculations. If our 5 marble diameters were 14.83 mm, 14.95 mm, 14.48 mm, 14.66 mm, and 14.72 mm, we would enter those numbers into the "Enter numbers separated by commas:" window, each separated by commas, and click on the Submit button. The result is

> Input numbers: 14.83, 14.95, 14.48, 14.66, 14.72
>
> 5 numbers were entered that total 73.64
>
> Average is 14.728
>
> Standard deviation = 0.17739785793521

So your answer is 14.728 ± 0.177 mm    Notice that the standard deviation needed to be rounded. It might also be satisfactory to use 14.73 ± 0.18 mm as the answer.

We then calculate the average volume of the marbles using the volume formula

$$V_{\text{average}}=\frac{4}{3}\pi r^3=\frac{1}{6}\pi d^3=\frac{1}{6}\pi(14.73\,\mathrm{mm})^3=1673\,\mathrm{mm}^3=1.673\,\mathrm{cm}^3$$

Notice: Although 1 cm = 10 mm, 1 $\mathrm{cm}^3$ is equal to 1000 $\mathrm{mm}^3$ .

Next, we are to determine the mass of each of the marbles on a sensitive weighing scale. I have a kitchen scale that has a resolution of 1 g and a maximum capacity of 5000 g. It has an "ounce" mode and a "gram" mode, but we want to use the gram mode. With a resolution of 1 g, we get 4 g for the marble. I have a better scale with a maximum capacity of 100 g and a resolution of 0.01 g. It gives a reading of 3.79 g for one marble. You may not have such a sensitive scale, so let's use pretend data for question 7. The 5 marbles might have masses of 4.30 g, 4.50 g, 4.09 g, 4.24 g, and 4.29 g which have an average of 4.28 ± 0.15 g.

> Note: There is a subtle, but important point about determing the mass of an object using a scale. **A scale measures the weight of something, not its mass.** Without gravity, a scale would read zero for everything. On the moon, it would give a reading 1/6 as much as on the Earth. On Mars its reading would be 38% of that on Earth. A scale measures force of gravity, not the mass of an object, but if we know a scale will be used only at the surface of the earth, we can make it show the mass of an object. This works because the pull of gravity is nearly the same everywhere on the surface of the earth. A device that measures mass independent of gravity, must shake the mass and show how much the object resists the shaking.

Question 9 on your measurement worksheet directs you to calculate the average densities of the marbles:

$$\rho=\frac{m}{V}=\frac{4.28\,\mathrm{g}}{1.673\,\mathrm{cm}^3}=2.56\,\mathrm{g/cm}^3$$

which is the density of the glass from which the marbles were made.

We invariably run out of time in the lab before we can do the exercises for questions 10-15, but you might look them over and imagine doing them.

## What you can do at home

For our online teaching, I must hope that you have a ruler with centimeters and millimeters on one side. When I first started teaching I went to Home Depot to buy a metric tape measure and couldn't find one. When I asked one store worker, he didn't understand what I wanted. I then asked another who immediately understood and directed me to a lonely 8-meter one in the very lower left of their display of 30 tape measures.

If you do not already have a metric ruler or tape measure, you could make your table measurements in our primitive US system and use Siri or some online app to convert them to metric. For example, if your table is 28 inches high, that converts to $28\,\mathrm{in}\cdot\frac{25.40\,\mathrm{mm}}{1\,\mathrm{in}}=711.2\,\mathrm{mm}$ . Since there are 1000 mm in 1 meter, this can be written as 0.7112 m. Or, since there are 10 mm in 1 cm, this can be written as 71.12 cm.

I prepared a handout showing metric rulers which is available at
*https://yosemitefoothills.com/Science-1A/MetricRuler-IfPrintedAt300dpi.png*
It will only be the correct size if printed at exactly 300 dots per inch. Unfortunately, many of you will not have a printer where you can specify 300 dots per inch, but it is available if you do.

Next, you need to find a rectangular or circular table at home to measure. If it is rectangular (ignore rounded corners), you can measure the length, width and height, and if necessary convert those measurements to millimeters, centimeters, and meters to fill in question 1 on the worksheet. If your table is circular, measure its diameter and height.

Most people will not have a micrometer or vernier calibers at home unless they work on cars. How can you then measure the thickness of a sheet of paper? A stack of 100 pages should be about 10 mm thick. It can be measured and then divided by 100. Unfortunately, that trick won't work for measuring your hair diameter. Laying 100 hair strands side-by-side would be difficult.

Measuring marble diameters without a micrometer or vernier caliber is a challenge. If you cannot figure out how, just pretend. Make up a set of 5 marble diameters and 5 masses similar to those given above, and calculate the averages, standard deviations, and glass density for your imaginary marbles.

Finally, a kilogram is 1000 grams, so that is the mass of about 300 marbles. I have a granite stone that I usually pass around that is very nearly 1 kg in mass. It is the size of a large fist.

If your bathroom scale can be set to read kilograms, weigh yourself with it to know your mass in kilograms. If your scale cannot show kilograms, convert your weight in pounds to kilograms by dividing by 2.20462. This is just for your personal information so you have a better understanding about the size of the kilogram mass unit. Also, determine your height in meters. It will be your height in inches multiplied by 0.0254.

(For example, my weight is 220 pounds which becomes 99.8 kg and my height 6' 4" which is 1.93 m.)

## Signal Averaging

Finally, look at the handout entitled "Signal Averaging" at
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/SignalAveraging.pdf* .
Then, play the animated gif at
*https://yosemitefoothills.com/Science-1A/Handouts/Week-01/ConstantSignalPlot.gif*
to see how the repeated averaging of a weak signal in noise eventually lets the signal become visible.

Another example of averaging is entitled "The Hubble Ultra-Deep Field in 3D". Here, the Hubble telescope averaged exceedingly weak light from a "empty" region in space for 10 days and revealed about 3000 galaxies. Watch that 4-minute YouTube video at
*https://www.youtube.com/watch?v=oAVjF_7ensg* .

## Lab Credit Points

To get credit points for this lab, send me an e-mail within a week or two saying that you:

Read this 5-page Lab note and made sure you understood its unit and scientific notation use.
Determined the metric size of a table.
Use first choice *https://yosemitefoothills.com/Calculator* to find the mean and standard deviation of the following 5 numbers: 14.52, 14.31, 14.57, 14.45, and 14.43.
Have determined your mass in kg and your height in meters? Don't report it, just say you know it.
Read the Signal Averaging handout mentioned above.
Watched the Signal Averaging animated gif.
Watched the Ultra-Deep Field YouTube video.