Introduction to Measurements of Physical Quantities

Content Discussion and Activities

PHYS 104L

1 Goal

The goal of this week's activities is to provide a foundational understanding regarding measurements of physical quantities. The importance of units, converting between different units, reading error as an ultimate limitation on measurement precision, and the use of a Vernier Caliper are primary topics to be covered.

2 Introduction

The scientific method involves observing phenomena, creating a model to explain those observations, using that model to make a prediction, collecting data to test that prediction, and then modifying that model if data proves inconsistent with it. A key part of this method is collecting data by making measurements of physical quantities. Correctly making and understanding measurements involves several key skills and concepts which students will be exposed to during the discussion and activities in today's lab.

3A Discussion - Measurements and Units

When most people think about measurements, they focus on numerical values. Such is reasonable as measurements tend to, indeed, involve numerical values. However, measurements for most all physical quantities must also include an appropriate set of units to go with the numbers, otherwise the information is of no use in describing the physical quantity. As a quick example, suppose you are planning to meet your friend at a store. They call you and tell you they will be a little late and ask you to meet them then. You ask how late do you think you'll be and they answer "About 10." This number, by itself, tells you nothing. 10 what? 10 minutes. 10 hours. Those are two very different situations. The number 10, by itself, doesn't describe the amount of time that your friend is running late. Minutes and hours are different **units** one can use to describe time. In order to describe most physical quantities, one needs to give both a numerical value and an appropriate set of units. In physics, we use a limited number of **fundamental dimensions** (length, time, mass, electric charge) to describe physical quantities. Each of those different **dimensions** have different **units** which can be used to describe them. Minutes and hours are two different units that could be used to describe a time interval. Other examples of common time units would be seconds, months, days, years, weeks. There are other uncommon units for time used for some special fields or situations. Some examples of units used to measure the dimension of length are inches, meters, centimeters, miles, feet, kilometers, and millimeters. Common units for mass are grams, milligrams, and kilograms while the common unit for electric charge is the Coulomb. Appropriate units for different physical quantities are either one of these dimensions or some combination of these dimensions. Consider speed as an example. A typical unit used for measuring the speed of a car is mph (miles/hour). This quantity has the dimensional form of LENGTH/TIME. Appropriate units for speed will always be some unit of length divided by some unit of time. While mph could be used, one could also use centimeters/hour or feet/second if desired. A key takeaway is that measurements require both a numerical value and the appropriate units to go with that value. The measurement is of no use without both parts.

3B Activity – Measurements and Units

1.) You will be given several objects. You will also have rulers with inch and cm measuring scales. You are to measure the length or width of the objects, recording those values, in both inches and cm.

2.) Next you will calculate the ratio of the measurement made in cm divided by the corresponding measurement made in inches. Do this by hand using a calculator.

3.) Take a look at how these ratios compare for different objects. Calculate the average of these calculated ratios. Do this by hand using a calculator.

4.) Use the **Excel** spreadsheet on the computer to create a table with 4 rows listing the object measured, the length in inches, the length in cm and the ratio similar to that shown in the activity sheet. Use the spreadsheet to calculate the ratio, instead of your calculator. Also use the spreadsheet to calculate the average of those individual ratios. Make sure the values from the spreadsheet match those from your calculator. The lab instructor will go over use of a spreadsheet with the class.

5.) Once all groups in the lab have completed step 3, collect the average ratio determined for each group and list them on your activity sheet. How do these values compare?

4A Discussion – Unit Conversion

Consider one of the objects for which you measured the length. That object has some length; however, notice that when you measure using the inch scale or the centimeter scale, you get different numerical values. Those different numerical values actually describe the same length; the same quantity. The reason you got different numbers is that you used different measurement scales based on **different units** for those measurements. A key point to notice is that the same physical quantity will be described with different numbers if you use different units for the measurement. This is why it is so important to always include both a number and the correct corresponding units when you make a measurement.

What is the significance of the constant ratio found in the activity? Due to the way those different length scales are defined, the definition of the INCH and the definition of the CENTIMETER, there is a clear relationship between those different sets of units. It turns out that 1.00 inches is equal to 2.54 cm. Take another look at your ruler and see how many cm correspond to 1 inch. About how many cm correspond to 2 inches? A similar relationship can be identified for any two units that describe the same physical quantity. In other words, there is a relationship between any two units of length or any two units of time. We will refer to these as Unit Conversion Relationships, and one such is 1.00 in = 2.54 cm. You are already familiar with some of these Unit Conversion Relationships, for example, 1 minute = 60 seconds. You can probably think of some other Unit Conversion Relationships that you already know. Other useful sources for Unit Conversion Relationships would be your textbook or the internet.

4B1 Activity – Unit Conversion

1.) Open a web browser and google "convert inches to cm". You should be able to quickly confirm that 1.00 inches is equal to 2.54 centimeters. Look up the Unit Conversion Relationship for "years" to "seconds" and "meters" to "feet" and record them on your activity sheet.

4A Discussion – Unit Conversion Continued

Knowing the appropriate unit conversion relationship allows you to convert a measurement in one set of units into a different set of units. When doing this, it is important to realize that you aren't changing the physical quantity you are describing, you are just changing the number you use to describe it because you are going to use a different set of units. The skill of unit conversion is an important one to know and understand. You may remember from high school that the number 1 has the special property that when you multiply anything by 1, you get the same thing back. Let's say we have a distance that we have measured, 219 cm. We want to know what that same distance is in units of inches rather than cm, in other words, we want to convert the units of that measurement from cm to inches. We can do so using the **Unit Conversion Relationship** 1.00 in = 2.54 cm. If those two units are equal to each other, then their ratio is 1. This relationship, then, gives us two different convenient ways of writing the number 1.

$$1 = \frac{1.00 inch}{2.54 cm} = \frac{2.54 cm}{1.00 inch}$$

If we take the original distance measurement we have, 219 cm, and multiply it by the number 1, we know that doesn't change the distance. By choosing the correct form of the number 1 to use (one of the two ratios) we can, however, change the units for that measurement. The question is, which ratio do we want to use? It turns out, the units have to follow the same math that numbers do when you multiply, add, subtract or divide measured values. Since our original measurement has units of cm, those are the units we are trying to get rid of. If we use the ratio that has cm in the denominator, those units will cancel out and leave us with a new number to describe that same distance and that new number will have units of inches.

$$219 cm \cdot \frac{1.00 inch}{2.54 cm} = 86.2 inch$$

219 cm and 86.2 inches are two equivalent ways of describing the same distance. Even though the numbers are different, they describe the same quantity because they are using different units. This is the reason the ratios you calculated in the first activity compared the way they did. Any

Unit Conversion Relationship can be used to write the number one in two different ways and these ratios can then be used to convert between those sets of units. If we had an original measurement in units of inches, say 42.1 inches, and wanted to convert that measurement into cm, we would use the other ratio as follows

$$42.1 \text{ in} * \frac{2.54cm}{1.00inch} = 107 \text{ cm}$$

Notice how, in this case, we used the ratio that had inches in the denominator to cancel out the original unit we were trying to convert away from. This same method is how you can always convert from one set of units to another. Find the needed Unit Conversion Relationship, use it to write the number 1 as a ratio and multiply such that the units you are converting out of cancel out leaving the units you want your measurement to have.

4B2 Activity – Unit Conversion

1.) Using the stopwatch at your table, time the event described by the instructor. Your stopwatch measures in units of seconds. Record this time.

2.) Showing your work and process on the activity sheet, convert this time interval into units of hours.

3.) Convert this time interval into units of years.

4.) The lab instructor will also specify an object for you to measure the length of in inches. Do so and record this value on your activity sheet.

5.) Again, showing your steps, convert this measurement into units of meters.

5A Discussion – Reading Error

Any measurement we make has some amount of uncertainty associated with it. We can't make an EXACT measurement. In other words, technically, a measurement actually has the form of Value $\pm$ Uncertainty. Understanding how big that uncertainty is and how to properly determine its value is an important part of understanding measurements. There are several different types of error sources that can cause uncertainty in a measurement and we will discuss some of these in later weeks. A fundamental limitation of the precision with which we can make a measurement is the **reading error** associated with the measuring device used to make a measurement. If there are **no other factors** affecting the precision of your measurement, the uncertainty in your measurement is the **reading error**. A good rule to follow is that the **reading error of a measuring device is the smallest increment of measurement** on that device. For example, a typical ruler with centimeter marks and millimeter marks on it has a reading error of $\pm$ 1 mm. If you measure a length and get 68 mm for the measurement, you know it is not likely the length is actually 68.0000000000 mm. The actual value could be 68.2 mm or 68.04 mm or 68.1002 mm and you'd have no way of knowing because your measuring device cannot measure down to that level of precision. You could safely say that your measured value for that length was 68 mm $\pm$ 1 mm. This measurement actually corresponds to a range of values; a range in which you think the actual value is located. You would be indicating that you are very confident the actual value for that length is somewhere between 69 mm and 67 mm. The only way you could narrow down that range would be to use a measuring device with a smaller reading error.

5B Activity – Reading Error

1.) For this activity, you will be measuring a particular time interval. You should have a small sand hourglass at your table. You will be measuring how much time it takes for the sand to run out once the hourglass is turned over. You will do this several times using different timers. The first stopwatch you will be using is a stopwatch program on the computer. Open the program “Stopwatch” via the desktop icon on the computer. You can use the “start”, “stop”, and “reset” buttons just as you would expect them to work on a regular stopwatch. Test it by clicking start, wait a few seconds and then click stop. Now click reset and you are ready to collect data. You will flip the hourglass and simultaneously click start. Just as the last sand falls, click stop and record this time interval on your activity sheet. Repeat this measurement for a total of 6 measured values.

2.) The second stopwatch you will use is also a stopwatch program; “E-tech Timer”. You can use the icon to open this program. Clicking “start” will start the timer and the start button will turn into a “pause” button that can be used to stop timing. There is also a separate “reset” button. Use this stopwatch to time the hourglass for 6 additional trials. Record these values on the activity sheet.

3.) Finally, use the hand held stopwatch at your table to measure the hourglass time interval 6 additional times. Record these values on your activity sheet.

4.) Identify the reading error for each of the different stopwatches and record that value on the activity sheet.

5.) For each measured value, write out a range each of the measurements corresponds to. Are the 6 ranges for the first set of data all in agreement with each other (do the ranges overlap)? What about for the second and third sets of data? How might you explain these results?

6.) Do the measurements from set one agree with those from set two and set three? Do the measurements from set two mostly agree with those from set three? Discuss why?

7.) Usually, measuring devices with smaller reading errors cost more money to acquire or use. Knowing this, does it always make sense to use a device with the smallest possible reading error when making a measurement? What if it cost you \$.10 per time to use the first stopwatch, \$.50 per time to use the second stopwatch, and \$2.50 per time to use the third stopwatch? Which stopwatch would be the best choice to use for measuring the hourglass time? Explain in the space on your activity sheet after discussing.

6A Discussion – Use of a Caliper

If the reading error for the measuring device you are using is too large, you need to get a measuring device with a smaller reading error. Usually, this corresponds to spending more money for a more expensive measuring device. At some point, the expense of getting a smaller reading error gets quite large. Meter sticks and rulers typically have markings in 1 mm increments on them yielding a reading error of ± 1 mm. This level of reading error is often acceptable, however, in some cases it is not. A Vernier Caliper is a device which allows us to reduce the reading error by at least a factor of 10 without a substantially higher cost. Your instructor will demonstrate and discuss the use of a Vernier Caliper for measuring lengths.

6B Activity – Use of a Caliper

1.) You will be given three different objects to measure. You will also be given three different measuring devices to use; a laminated grid paper with 1/2 cm spacing, a ruler, and a Vernier Caliper. Measure the width or length of the objects using the grid paper. Record these measurements on your activity sheet in the form of Value ± Reading Error.

2.) Repeat this process using the ruler.

3.) Repeat this process using the Vernier Caliper.

4.) Check to see if the 3 measurements for a particular object are in agreement with each other or not (do the ranges overlap)? Check this for each object. If they do not agree, double check your measurements.

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Activity Data Sheet

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Activity 3B

Object								
Length (cm)								
Length (in)								

Ratio (cm/in)								

How do the ratios compare?

Average Ratio = ________________ cm/in

Average Ratios from Other Groups in Lab

How do these values compare with each other?

How do these values compare with yours?

Activity 4B1

Unit Conversion Relationship “years” → “seconds” ________________________________

Unit Conversion Relationship “meters” → “feet” __________________________________

Activity 4B2

First Event Description ____________________________________

Measured Time __________________ seconds

Convert to hours:

Convert to years:

Object Measured ____

Measured Length __________________ inches

Convert to meters:

Activity 5B – Reading Error

Stopwatch used	Trial 1 (sec)	Trial 2 (sec)	Trial 3 (sec)	Trial 4 (sec)	Trial 5 (sec)	Trial 6 (sec)
“Stopwatch”						
“E-tech Timer”						
Hand Stopwatch						

	“Stopwatch”	“E-tech Timer”	Hand Stopwatch
Reading Error (sec)			

“Stopwatch”	Range	“E-tech Timer”	Range	Hand Stopwatch	Range
Trial 1		Trial 1		Trial 1	
Trial 2		Trial 2		Trial 2	
Trial 3		Trial 3		Trial 3	
Trial 4		Trial 4		Trial 4	
Trial 5		Trial 5		Trial 5	
Trial 6		Trial 6		Trial 6	

Describe whether the different ranges agree or not?

Step 7 Question Answer

Activity 6B

Object Measured			
	Range (cm)	Range (cm)	Range (cm)
Using Grid Paper			
Using the Ruler			
Using the Caliper			

Do the measurements for the first object agree with each other? Explain?

Do the measurements for the second object agree with each other? Explain?

Do the measurements for the third object agree with each other? Explain?

What do these results tell you about the "other factors" that might be affecting the precision of your measurements?