# Experiment 2
# Measurements - Length

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Name:



Date:

## Key Objectives

1. Understand Accuracy and Precision.
2. Identify what type of measurements need to be made to determine accuracy and precision.
3. Understanding how to take and report measurements with the proper number of significant figure.
4. Make length measurements with a variety of measuring devices.
5. Use of Dimensional Analysis in routine calculations.

## Discussion

### Accuracy and Precision

Through observation of the world around us both qualitatively and quantitatively we as scientists seek to formulate hypothesis, theories, rules and laws to describe how matter behaves. Our ability to acquire accurate and precise data is crucial to our success as scientists. In this (and the next few) experiments we will learn how to obtain correct measurements that are as accurate and precise as possible.

The **Accuracy** of a measurement or calculation is how close the result is to the correct value. This is most often determined by making measurements on known materials and comparing the measured value to the accepted (or literature) value. The correct values used to be tabulated in the *Handbook of Chemistry and Physics* but usually these values can now be found on the internet, though one should always used a reputable site like NIST - National Institute of Standards and Technology or check several site to see that the correct values agree with each other.

The **Precision** of a measurement or calculation is how reproducible the result is if the experiment is performed multiple times or how close repeated measurements are to each other. In practice this means that you must take many measurements of an observed quantity to determine how precise your measurement is.

### An Analogy for Accuracy and Precision

The term precision and accuracy are often confused by students. A representation of the differences can be seen in Figure 2.1. Precision is how close each $\times$ is to each other, while accuracy is a measure of how close the $\times$ is to the center of the target. The worst measurements are represented by the first target which is neither precise nor accurate. The best measurements are represented by the fourth target which is both precise and accurate. Targets two and three represent precision or accuracy but not both at the same time and either target could be an acceptable measurement depending on the requirements of the measurement. We always strive for both accuracy and precision but quite often there is not time in lab to do both, in which case it is important to know whether you measured something accurately or precisely.

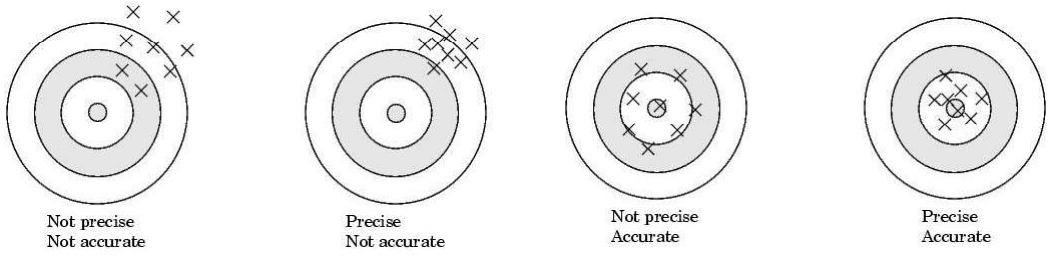



Figure 2.1: Targets illustrating the 4 possible combinations of accuracy and precision. Credit: unknown

### A More Detailed Look

The accuracy and precision of a measurement in an experiment can also be visualized using probability densities. In Figure 2.2 we have a Gaussian distribution of measured values, the accuracy of the distribution is determined by how close the average measurement is to the correct value, while precision is determined by the width of the Gaussian curve. Just like with target shooting, there are 4 possible combinations of accuracy and precision.

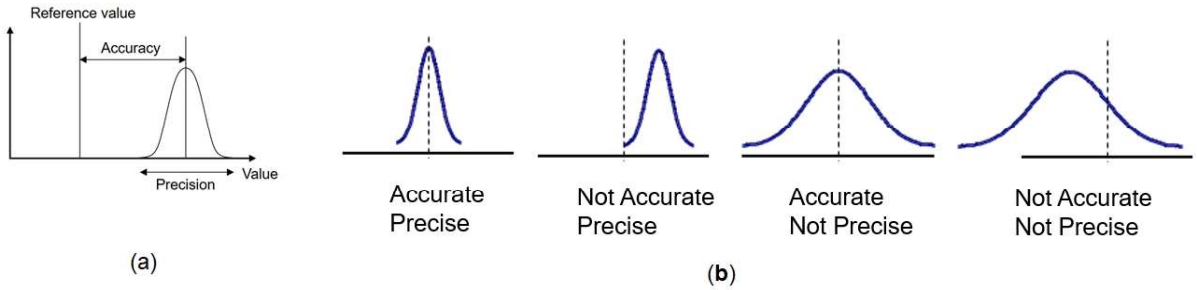



Figure 2.2: (a) Graph illustrating accuracy and precision of a measurement. (b) The 4 possible combinations of accuracy and precision. credit: (a) `https://commons.wikimedia.org/wiki/File:Accuracy_and_precision.svg` (b) author

**Key Idea: Accuracy and Precision**

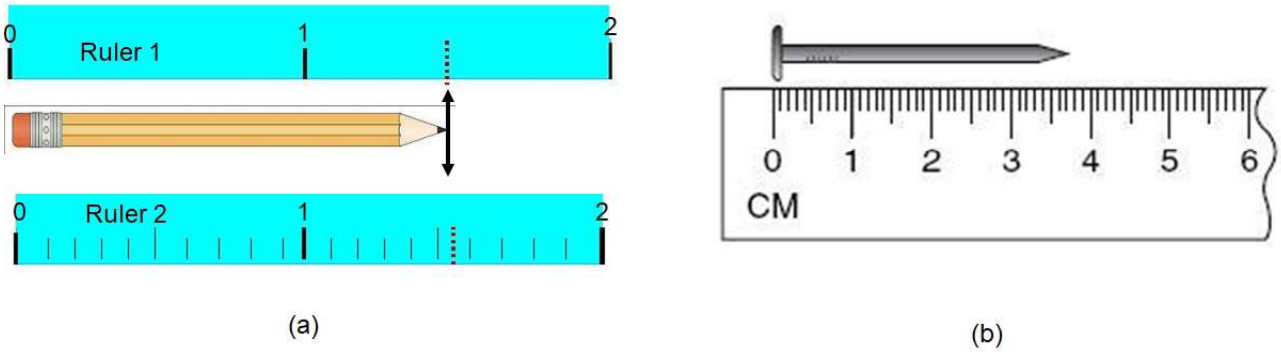
**Accuracy** - how close a measurement is to the correct answer. Measure a known value.
**Precision** - how close repeated measurements are to each other. Make multiple measurements.

### Making Measurements in Lab

Scientific measurements always contain some amount of error in them. Even something as simple as counting the number of people the class room could result in errors if someone is counted twice or is out of the room using the bath room. Another example would be measuring the height of a person, did they have their shoes on or off, did they stand straight or slouch, are they bald or have lots of hair.

Even the devices used to make measurements are subject to error, often making it impossible to obtain the exact same measurement repeatedly. For example when you step on your bathroom scale it rarely reads the same weight. To indicate how well a measurement is made, record all the digits of the measurement using the markings that are known exactly and one further digit that is estimated or uncertain. The estimated or uncertain digit is obtained by noting the smallest unit of measurement

given and then estimating between the values. These digits are collectively referred to as **significant figures.** Significant figures represent how well a measurement is made, the more significant figures in the measurement the better it is considered. Significant figures do not represent how accurate or precise a measurement is only how well you can make the measurement.




(a) (b)

Figure 2.3: (a) Measuring a pencil with two different rulers will result in a different number of significant figures. (b) Anther example of how to read a ruler. credit: (a) author (b) unknown

For example in Figure 2.3 shows how one would report a measurement depends on what ruler is used to measure the pencil. Using the Ruler 1, the first digit is certainly 1, but we must estimate the tenths place. The length of the pencil, using Ruler 1, and written using the proper number of significant figures, would then be 1.5 inches, where the tenths place is an estimate. The second ruler has additional markings and allows a measurement with more significant figures to be made. The pencil is certainly between 1.5 and 1.6 inches, and we then must estimate the hundredths digit. The length of the pencil using Ruler 2 would be written as 1.55 inches.

In another example, the ruler shown in Figure 2.3 has large marks every 1 cm, and smaller marks every mm. The length of the nail is certainly between 3.7 and 3.8 cm, thus indicating at least 2 significant figures. However, you can add one more digit to your reported value by estimating the value between the lines. Thus, you could report the length of the nail as 3.75 cm, where the last digit represents your "estimated" value. The first rule is one should always try to "'read between the lines"'. A second rule to remember when making measurements is that if the length of the nail was exactly on the 4 cm line, you should indicate the number of significant figures to which you can make this measurement by adding zero's to your value and record the length as 4.00 cm.

The precision in a measurement is often quoted in terms of how inaccurate the estimated digit is. For example in Figure 2.3 the precision would be stated to be $\pm$ 0.05 cm. The $\pm$ indicates that the measurement could be shorter or longer then the stated value. The 0.05 cm indicates two things, first the number of places past the decimal point it is possible to read (in this case 2) and the precision to which the last digit can be estimated (in this case you can probably distinguish if a length was 1/2 way between the two millimeter marks (0.05 cm), but can not guess if it was 0.01 or 0.02 cm).

**Key Idea: Making Measurements**

Remember, **ALWAYS** read between the lines, and report measurements to as many decimal places as possible, using zeros to indicate additional precision if needed.

## Procedure

To get you started performing measurements we will begin with a few simple exercises. Be sure to record data in the appropriate places in the results section as you complete each measurement. **All** results should be written with the proper number of significant figures and units. **ALL** calculations should be shown in the space provided.

### Small Ruler

1. Measure the length of the following lines as accurately as possible using **centimeters.**
   Line 1: _____ Line 2: _____
2. Make sure to record to the proper number of significant figures and include units in your answer.

### Meter Stick

1. Measure the length and width of a piece of paper as accurately as possible using a meter stick in **centimeters.**
2. Measure the height of the lab bench.

### Wood Block

1. Write down the Identity (ID) of the block.
2. Measure the Length, Width, Height of the block.
3. Calculate the volume of the block (Volume = L $\times$ W $\times$ H). Be sure to use the proper number of Significant Figures and units in your answer.
4. Check your answer with the instructor.

## Results

All results should be written with the proper number of significant figures and include units. **ALL** calculations should be shown in the space provided.

### Small Ruler

1. Length can be measured with the smaller ruler with what uncertainty? ($\pm$): _____
2. Length of the first line _____
3. Length of the second line _____

### Meter Stick

1. Length can be measured with the meter stick with what uncertainty? ($\pm$): _____
2. Length of a piece of paper _____
3. Width of a piece of paper _____
4. Height of the Lab Bench. _____

### Wooden Block

1. Identity of the wooden block _____
2. Length _____
3. Width _____
4. Height _____
5. Volume _____
6. Correct Answer (Check with instructor) _____

## Questions

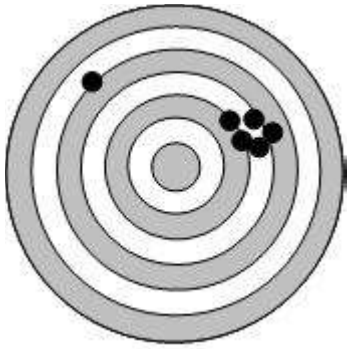
1. What **two** rules should one remember when measuring (in general, and specifically when using a ruler)?

2. The directions for an experiment state "cut a piece of chromatography paper 2.7 cm long".

   (a) Give the minimum length of paper that would satisfy these directions. 2(a) _____

   (b) Give the maximum length of paper that would satisfy these directions. 2(b) _____

3. Discuss the precision **and** accuracy of the shooter given the following target. Explain.



4. Bob was measuring the length of the class room using a meter stick. Bob said the room is 2000 cm long. What is wrong with Bob's answer? What should Bob's answer have been?