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Lab 2 – Measuring Instruments

Purpose

We will now take the knowledge and experience you gained in Experiment 1 and apply it to particular measurement tools in this experiment. From now on we simply expect you to just do everything we learned in Experiment 1, that is, proper units conversion techniques, calculating in scientific notation correctly, keeping three sig figs or more if the problem demands it, problem solving using SOLVE, dimensional analysis, handling error, graph, fitting data, and transforming data. In this lab we will cover using the ordinary ruler, mass balance, Vernier caliper, micrometer, and graduated cylinder. While this does not represent every measurement instrument we use in physics, what we learn here is applicable to most other measurement tools.

Equipment

- Balance
- Vernier Caliper
- Metric Micrometer
- Meter Stick
- Graduated Cylinder
- Cylindrical Object
- Spherical Object
- Solid Copper Wire
- Piece Sheet Metal
- Irregular heavier than water object
- Calculator
- Ruler

Theory

A. Ordinary Ruler and Graduated Cylinder

The ruler or meter stick was discussed in detail in the first lab. Figure 1.3 is reproduced here for review.

A graduated cylinder is a cylinder with a graduated scale, like a ruler's scale, along the side. Read it just like a ruler, but exercise care to avoid parallax errors. Figure 1.7 is reproduced here for review to avoid parallax errors with relevance to the graduated cylinder.

There is one subtlety when reading a graduated cylinder. Often we measure water level and water has surface tension, that is, it rides a little up the side as shown in Figure 2T.1. Since the distance up a wall water can rise varies and is hard to see, it's easier simply to take all measurements from the bottom. Refer to Figure 2T.1

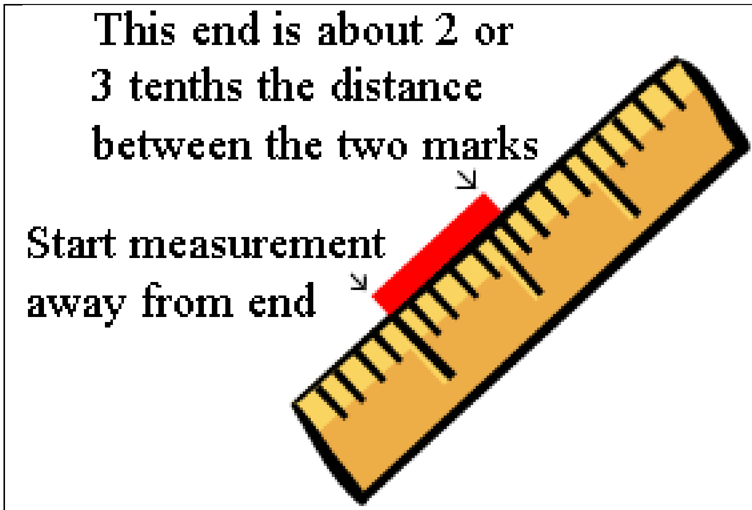

Figure 1.3 – Start measurements from a midpoint on a ruler and estimate that next digit. If this ruler's major divisions (long lines) are 1 cm apart, then the length of the red object is about 1.24 cm to 1.26 cm. Different people may estimate the third digit differently. That's OK. In this example report the measurement to 3 sig figs and, if there is disagreement among observers, then report all values.

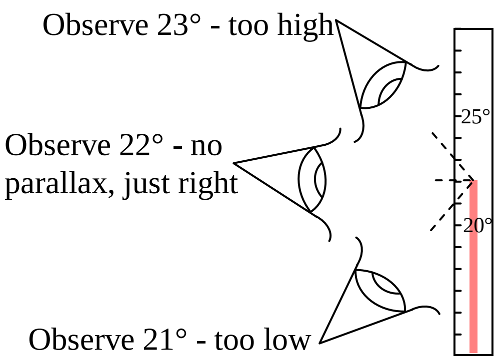

Figure 1.7 – If all else fails, take readings as close to perpendicular, 90°, as possible.

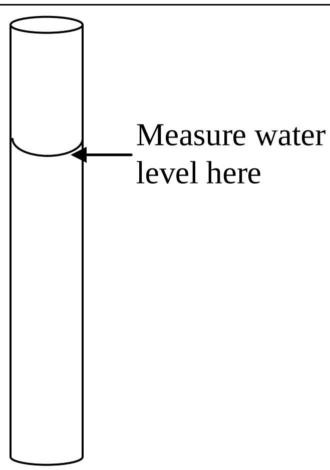

Figure 2T.1 – Measure water level from the bottom of the meniscus and be sure to minimize parallax errors.

B. <u>Laboratory Balance</u>

We commonly use a triple beam balance. It's called that because there are three beams with known masses that we compare the unknown mass against. Figure 2T.2 shows pictures of several models. In a three beam balance, a heavy mass is on one beam, a moderate mass on the second, and a light mass on the third. A typical triple beam balance has a least count of 0.1 gm, but you may interpolate (doubtful figure) to 0.01 gm. If you add a fourth beam you can add an even lighter mass for an example least count of 0.01 gm. A fifth beam and you get even lighter yet – least count of 0.001 gm. In general, the more beams, the more accurate the mass balance is. Some balances are enclosed to prevent air current from influencing measurements. Very sensitive balances are on heavy platforms to prevent vibration. One type of balance you put the object on a plate above the balance. In other types a pan hangs down much like the scales of justice.

(a) (b) (c)

Figure 2T.2 – Picture of three types of mass balances. (a) common beam balance, (b) old style scales of justice balance, and (c) pan balance useful for measuring the difference in mass between two samples.

One commonality of all balances is that known masses are compared to the unknown mass. They measure mass, not force. The measurement would yield the same result if performed on the Moon. The weight (*mg)* would certainly change, but the weight of the known masses also changes be the same factor. In contrast, a spring scale, of which a bathroom scale is one example, would read differently on the Moon. It takes a precise amount of force to stretch or compress a spring a certain distance and, therefore, spring scales measure FORCE and not mass. Now we all know if you put your finger on a balance (add force), you can make it move. You're just comparing your applied force with the force of gravity of the known masses. So you may measure force with a mass balance, however if you do be sure to calculate the force. In general, however, it's a wiser just to use a spring scale to measure force.

Electronic balances are becoming more and more popular. In essence they are sophisticated spring scales that electronically measure the spring deflection. They also have functions programmed into the electronics to perform common tasks such as zeroing the balance (push the "tare" button).

A commonality between force sensors, including spring scales, electronic balances, and mass balances, is THEY MUST BE ZEROED. Check to insure that when nothing is on it, it reads zero.

This is a general overview which may enable you to use most mass balances, however there may be subtleties involved that may require reading the instructions for a particular model. Your instructor may be able to help, but we're trying to get you used to figuring things out on your own. Therefore, don't hesitate to pick up the instruction book.

C. <u>Vernier Caliper</u>

This device employs an ingenious trick invented by Pierre Vernier in 1631, that is, before electronics. A typical Vernier caliper has one scale (usually the moving scale) with 11 hash marks spaced at 0.9 mm apart sliding against another scale that looks much like an ordinary ruler with normal spacing (that is, hash marks are 1 mm apart). When fully closed the first and second scales (should) line up zero to zero. When we move the first scale 0.1 mm, the first line is aligned to a mark on the second scale. When moved 0.2 mm, the second line is aligned, 0.3 mm the third line, 0.4 mm the fourth line, and so on. When we move it an entire mm, the zero on the first scale lines up with the 1 mm mark on the second. The same is true when we move the slider 2 mm, 3 mm, 4 mm, etc. Figure 2T.3 has a few examples (from web site http://www.upscale.utoronto.ca/PVB/Harrison/Vernier/Vernier.html) to help you practice. The least count of the Vernier caliper described in this paragraph is 0.1 mm and it's difficult to estimate more precisely than this.

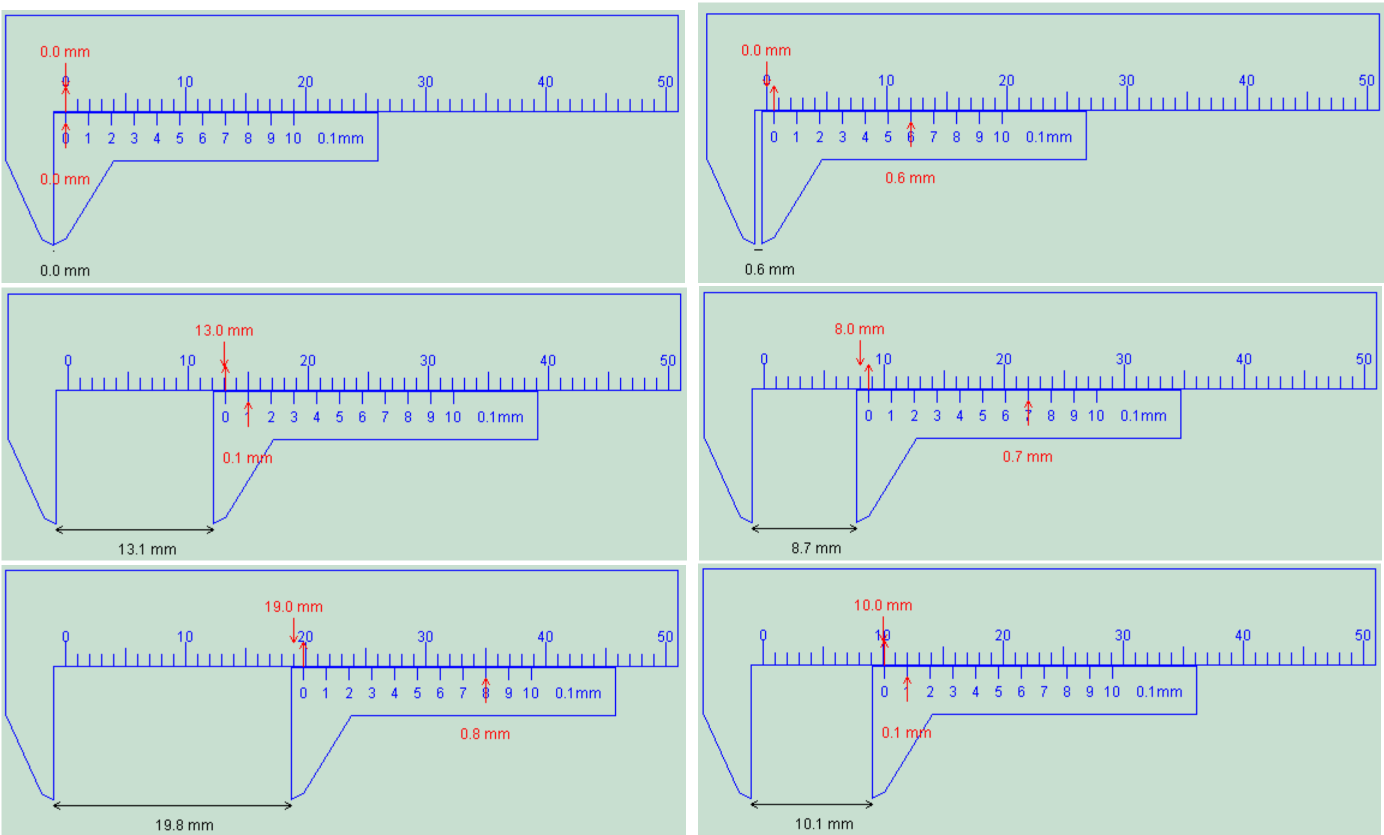

Figure 2T.3 – Examples of how to read a Vernier caliper.

The principle of the Vernier scale can be used in many ways. A more precise caliper might have 20 marks in 19 mm. So the first mark lines up when moved only 0.05 mm. A Vernier scale can be added to a micrometer giving one more digit of precision. Angular measurements might have hashes 0.5° (30') apart with a Vernier scale with 30 marks in 29'. This enables angular measurement precise to 1.0'. After this lesson we expect that when you encounter a Vernier scale in any context in the future, with a little inspection and practice you'll know how to read these instruments.

While a Vernier caliper is not prone to go out of calibration, most of the time it also cannot be zeroed. If when fully closed a Vernier caliper does not read zero, you will need to make the adjustment. If it reads, for example, 0.5 mm it will be necessary to subtract this from readings. If, for example, it reads -0.5 mm, you will need to add this to readings.

D. *<u>Micrometer</u>*

The micrometer (aka, mike) is based on the screw. If you go to the hardware store you'll notice metric sizes specified in, for example, M3x.5. The first number refers to the screw diameter in mm, but the number after the x (the second number) tells us how far the screw advances in mm in one revolution, aka pitch. The English system you may be used to is a little different and I'll leave it up to you to look it up since in science we stick with the metric system. The micrometer is based on the screw with a big, fat, cylindrical head with a scale marked on it. A common micrometer when rotated one revolution travels 0.5 mm and the cylindrical "thimble" has 50 marks thus the least count is 0.01 mm. But there are variations, therefore, study the particular model you will use. Add a Vernier scale to the example micrometer and the least count is 0.001 mm = 1.0 micrometer, hence the name, micrometer. While spelled the same, pronunciations have diverged over the years and sound different now.

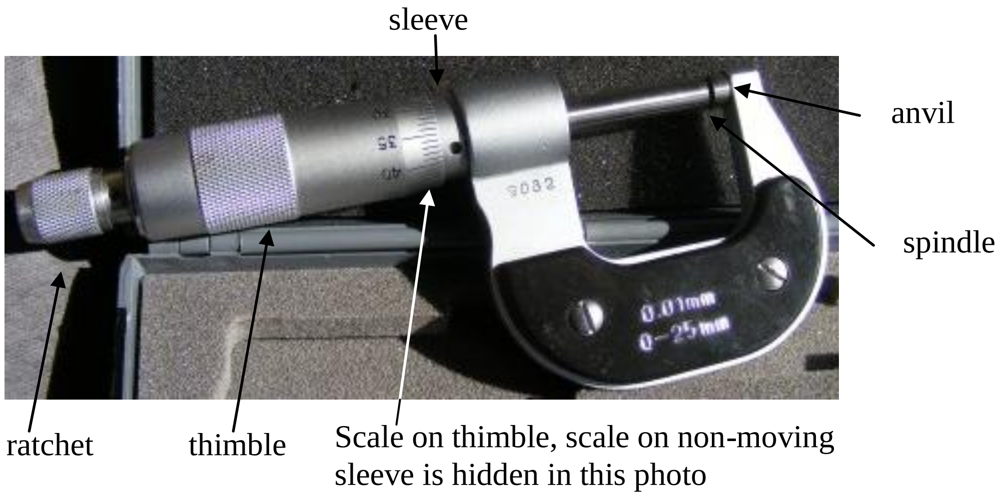

Figure 2T.4 – Micrometer showing parts: anvil, spindle, sleeve, thimble (part you rotate), and ratchet.

From: http://www.flickr.com/photos/free-stock/5000494740/sizes/o/in/photostream/

The micrometer also has a useful device – a ratchet. Use this and it insure the same force is exerted on every item measured – it aids in the precision of measurements.

Finally, be sure to zero the micrometer. This is a common theme – you always need to zero instruments.

E. <u>Density</u>

We'll work much more with this when we discuss buoyant force and Archimedes' Principle. Archimedes figures prominently in our understanding of density. He lived a long time ago, circa several hundred BCE, in Syracuse in Sicily. The King Hieron II suspected a goldsmith was cutting the gold with other metals (like copper and silver) to make a crown with the same mass as the amount of gold the king provided the goldsmith. The king couldn't figure this out so he called in his favorite scientist – Archimedes. Legend has it that Archimedes couldn't figure this out so, to relax, he took a bath. In those days they didn't have indoor plumbing, so you went to a place where they boiled water and mixed it in a tub for customers. Check out western movies ("The Good, The Bad, and the Ugly" or "Maverick" for example) to get the idea of how people took baths before indoor plumbing. Archimedes' bath was filled to the brim and when Archimedes got in the water overflowed. Suddenly the answer came flooding to his mind. He realized that the volume of the overflowing water equaled the volume of the object sunk in the water. Archimedes was so excited that he jumped out of the tub and ran home naked in public through the streets of Syracuse shouting "Eureka, eureka," which in Greek means "I found it, I found it."

Density is simply the ratio of mass to volume. We've had a means to measure mass for some time. Archimedes figured out how to measure volume of an irregularly shaped object. Prior to that, he surmised that different substances will have different density even if they have the same mass. We'll measure volume directly and by water displacement both to calculate density.

Here are a few formulas for volume of regular objects:

Box (rectangular prism, l = length, w = width, h = height) $\qquad V = l \times w \times h \qquad$ ***Equation 1.1***

Cylinder (A = cross-sectional area, r = radius, l = length) $V = Al = (\pi r^2)l$ ***Equation 1.2***

Sphere (r = radius $V = \frac{4}{3}\pi r^3$ ***Equation 1.3***

To get the volume of an irregularly shaped object use the graduated cylinder. Put some water in and read the volume, V_o, in ml. Then put the object in and read the final volume, V_f. $V_f - V_o$ equals the volume of the object.

<u>Procedure</u>

A. *Understanding Measurement Instruments*

1) What is the least count and doubtful figure for each of the measurement tools listed in the equipment list, that is, balance, Vernier caliper, metric micrometer, meter stick, and graduated cylinder? Enter you answers in Table 2R.1. Recall what least count is from Exp 1.

B. *Estimating Number of Pages*

2) Estimate the number of sheets (pieces of paper – equal to the number of pages if each page is printed on one side of a sheet and equal to half the number of pages if each page is printed on both sides of a sheet) in your textbook by doing the following: Zero your instrument and have group members each measure the thickness of one page and 10 pages and record this in Table 2R.2.
3) Next, (is your instrument zeroed?) have lab group members measure the thickness of all pages in your book. Start with Page 1 and end with the last numbered page in your book. Do not include appendices, indexes, and Roman numeral pages. Record this in Table 2R.2.
4) If the book in Procedure 3 is printed on one side of the sheet only then the page number of the last page is the number of sheets in the book. Record this in Table 2R.1. If the book in Procedure 3 is printed on both sides of the sheet, the the number of sheets equals the page number of the last page divided by two. Calculate this and record the number of sheets in Table 2R.2.
5) Determine the formulas to find the computed number of pages and record these formulas below Table 2R.2.
6) Calculate mean and standard deviation of thickness, computed number and percent error of the number of sheets, and record results in Table 2R.2.

C. *Measuring and Calculating Density*

7) Measure the masses (don't forget to zero the mass balance) of the objects and record this in Table 2R.3.
8) Measure (don't forget to zero) the dimensions of the objects given, calculate their volumes per Equations 1.1 to 1.3, calculate means, standard deviations, percent deviations, and measured density, and record in Table 2R.3. Note, it's beyond the scope of this course to understand propagation of error analysis, however the percent deviation for volume will equal the percent deviation for density. A table of densities follows.
9) Record the material the objects are made from, the accepted density, calculate percent errors, and record this in Table 2R.3. A table of densities follows.

Table of Accepted Densities

Complete Table of Densities (at http://www.periodictable.com/Properties/A/Density.html)

Solids	$\rho\left(\frac{gm}{cm^3}\right)$	S.G. (Specific Gravity) – no units
Gold (Au)	19.3	19.3
Lead (Pb)	11.3	11.3
Silver (Ag)	10.5	10.5
Copper (Cu)	8.9	8.9
Steel (Fe)	7.8	7.8
Tin (Sn)	7.29	7.29
Zinc (Zn)	7.14	7.14
Aluminum (Al)	2.7	2.7
Balsa Wood	0.3	0.3
Oak	0.8	0.8
Earth Average	5.52	5.52

Liquids & Gases	$\rho\left(\frac{gm}{cm^3}\right)$	S.G. (Specific Gravity) – no units
Mercury (Hg)	13.6	13.6
Water	1.0	1.0
Oil	0.9	0.9
Alcohol	0.8	0.8
Antifreeze	1.125 (32°F) 1.098 (77°F)	1.125 (32°F) 1.098 (77°F)
Air	$1.29*10^{-3}$	$1.29*10^{-3}$
Hydrogen	$9.0*10^{-5}$	$9.0*10^{-5}$
Oxygen	$1.43*10^{-3}$	$1.43*10^{-3}$

Post-Lab Questions – Answer on a separate page and attach

10) What are the probably sources of error when estimating the number of pages in your book? Which procedure was more accurate – measuring a single page or measuring 10 pages? Which procedure was more precise?
11) Does your answer to Question 10 suggest the better instrument, the micrometer or Vernier caliper, to use? Why or why not? Did you use the instrument that gave the most precise and/or accurate result?
12) How would air bubbles sticking to the irregularly shaped object influence the measured density? Would you expect the measured density to be greater than or less than the true density? Why or why not? Explain.
13) Examine Table 2R.3. For which object did you obtain the more precise measurements of density? The least precise? The most accurate? The least accurate? Explain these results.
14) If you had an irregularly shaped object that floats, how would you measure its volume? Explain thoroughly.
15) What is the mass of a steel ball 1 cm in diameter?
16) In the Theory Section, Part E, we discussed Archimedes. Now you finish. How would you determine if the crown was pure gold or not? Explain.

Lab 2 Report: Names ____

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Table 2R.1 – Least Count and Doubtful Figure (what's the smallest value you can estimate) of Measuring Instruments

Instrument	Least Count ( )	Doubtful Figure ( )
Balance		
Vernier caliper		
metric micrometer		
meter stick		
graduated cylinder		

Table 2R.2 – Estimating the number of pages in your textbook

Group Member	Single Page Thickness ( )	Thickness of 10 Pages ( )	Thickness of all Pages ( )
1			
2			
3			
4			
5			
mean			
standard deviation			
percent deviation			
computed number of pages			------------NA------------
actual Number of Pages			
percent error			------------NA------------

Write down the formulas to calculate the computed number of pages for each column.

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Table 2R.3 – Calculating Density

	Cylinder			Wire		
mass ( ) =						
group member	Diameter ( )	Length ( )	Volume ( )	Diameter ( )	Length ( )	Volume ( )
1						
2						
3						
4						
5						
mean						
standard deviation						
percent deviation						
measured density ( )						
object's material						
accepted density ( )						
percent error						

Table 2R.3 continued

	Sphere		Rectangular Prism				Irregular Object
mass ( ) =							
group member	Diameter ( )	Volume ( )	Length ( )	Width ( )	Height ( )	Volume ( )	Volume ( )
1							
2							
3							
4							
5							
mean							
standard deviation							
percent deviation							
measured density ( )							
object's material							
accepted density ( )							
percent error							