<u>Objectives</u>

The objective of this experiment is to acquaint the student with basic principles of using measurement instrumentation and to help the student become familiar with several measuring devices used in physics labs. Particular emphasis should be given to the use of the Vernier scale, the treatment of significant figures, and the reporting of percent error.

<u>Theory</u>

Four Basic Measurement Principles

- Always determine where "zero" is on the instrument and account for any offset.
- Always determine the units of the instrument's measurements.
- Don't let your eye fool you. Double check the reading. ("Measure twice; cut once!")
- Confirm that your measurement makes sense, based on an experimental sense of sizes.

Vernier Caliper

When using a meter stick, it is necessary to estimate the tenths of millimeters (the fractional parts of the smallest scale divisions). The vernier scale is a device which assists in the accurate reading of the fractional part of a scale division. The vernier caliper consists of two scales: one is the fixed main scale of the instrument, and the other (called the vernier scale) is arranged to slide along the fixed scale.

With the vernier calipers used in this lab, the principle divisions on the main scale represent centimeters and are further divided into tenths of centimeters, or millimeters. The vernier, or movable scale, contains ten divisions, each of which is nine-tenths as long as the smallest main-scale division. Hence, the ten divisions on the vernier scale have the same length as nine divisions on the main scale (see Figure 1).

The distance between the jaws of the instrument is always exactly the same as the distance between the zero marks on the two scales. In Figure 1 one can see that both the zero and the ten mark on the vernier coincide with some mark on the main scale. The first mark beyond the zero on the vernier is one tenth of a main-scale division short of coinciding with the first line beyond the zero on the main scale. This difference between the lengths of the smallest divisions on the two scales represents the least amount of movement that can be made and read accurately and is called the least count of the instrument. If the vernier scale is moved 1/10 mm, the next mark beyond the zero coincides with a main-scale mark (Figure 2). If moved until mark two coincides with a main-scale division, the total distance moved is 0.2 mm. Thus it is seen that we can get an accurate setting for tenths of a millimeter and not have to estimate them as on a meter stick.

In Figure 3 we see that the zero on the vernier lies between the 6 and 7 mm marks, and since the third mark on the vernier scale makes coincidence, the fractional distance is 0.3 mm, and the complete reading is 6.3 mm or 0.63 cm. By similar reasoning, the reading in Figure 4 may be seen to be 3.7 mm, or 0.37 cm.



Density

Different substances differ greatly in their physical properties, a fact that makes it possible to use these properties in their identification. Among these properties is density. Density, ρ (pronounced "rho"; it is NOT the letter "p") is defined as the ratio of the mass, m, of a sample of substance to its volume, V; that is,

 $\rho = m/V$

Commonly, the density is given in g/mL or g/cm^3 , but the SI unit is kilograms per cubic meter (kg/m³). If the object is not solid, or is not completely one single substance, the density calculated from measurements will differ greatly from any published standard density.

In this experiment you will have to calculate the volumes of several cylinders using the formula

$$V = \frac{\pi d^2 L}{4} = \pi r^2 L$$

where d is the diameter, r is the radius, and L is the length of the cylinder. Wires can be considered to be cylinders.

The volume of a sphere can be calculated using $V = \frac{4 \pi r^3}{3}$

while the volume of a rectangular solid can be found from V = lwh, where l is the length of a face of the solid, w is the width of the solid, and h is the height, or depth, of the solid.

Percent Difference and Percent Error

Sometimes scientists will want to compare their results with those of others, or with a theoretically derived prediction. Each of these types of comparisons call for a different type of analysis: percent difference and percent error, respectively.

Percent Difference: Applied when comparing two experimental quantities, E_1 and E_2 , neither of which can be considered the "correct" value. The percent difference is the absolute value of the difference over the mean times 100%.

% Difference =
$$\frac{|E_1 - E_2|}{\frac{1}{2}(E_1 + E_2)} \bullet 100\%$$

Percent Error: Applied when comparing an experimental quantity, E, with a theoretical quantity, T, which is considered the "correct" value. The percent error is the absolute value of the difference divided by the "correct" value times 100%.

$$\% \operatorname{Error} = \left| \frac{\mathsf{T} - \mathsf{E}}{\mathsf{T}} \right| \bullet 100\%$$

Guidelines for Using Significant Figures

Careful consideration must be given in scientific work to write the proper number of significant figures. In general, it is fairly easy to determine how many significant figures are present in a number by following these rules:

- Any digit that is not zero is significant. Thus 845 cm has three significant figures, 1.234 kg has four significant figures, and so on.
- Zeros between nonzero digits are significant. Thus 606 m contains three significant figures, 40,501 kg contains five significant figures, and so on.
- Zeros to the left of the first nonzero digit are not significant. Their purpose is to indicate the placement of the decimal point. Thus 0.08 L contains one significant figure, 0.0000349 g contains three significant figures, and so on.
- If a number is greater than 1, then all the zeros written to the right of the decimal point count as significant figures. Thus 2.0 mg has two significant figures, 40.062 mL has five significant figures, and 3.040 dm has four significant figures. If a number is less than 1, then only the zeros that are at the end of the number and the zeros that are between nonzero digits are significant. Thus 0.090 kg has two significant figures, 0.3005 L has four significant figures, and so on.
- For numbers that do not contain decimal points, the trailing zeros (that is, zeros after the last nonzero digit) may or may not be significant. Thus 400 cm may have one significant figure (the digit 4), two significant figures (40), or three significant figures (400). We cannot know which is correct without more information. By using scientific notation, however, we avoid this ambiguity. In this particular case, we can express the number 400 as 4 x 10² for one significant figure, 4.0 x 10² for two significant figures, or 4.00 x 10² for three significant figures.

<u>Apparatus</u>

Electronic balances (square and round pan) Metric ruler Vernier caliper 50 mL graduated cylinder Wires (silver, shiny copper, burnt copper) Metal cylinders (silvery and brown) Metal ball Metal rectangular solid Irregular solid (cylinder with a cavity)

<u>Procedure</u>

Note: **Each person should make an independent measurement for each quantity**. Then use the group average as the value obtained. Each measurement and the average should be presented in a data table. **Be sure to use correct significant figures**.

- 1. Determine the mass of each of two different types of metal cylinders (e.g. silver and brass-colored) using the square-pan electronic balance. Be sure to check the units that the balance is using (it should be measuring in grams).
- 2. Determine the mass of the sphere, the rectangular solid, and the irregular solid using the square-pan balance.
- 3. Determine the mass of each wire, using the round-pan balance. Note that the round-pan balance provides an extra digit of precision behind the decimal.
- 4. Measure the diameter of each cylinder and of each wire with the vernier caliper. Each person should take three readings at different places for each set of measurements. The readings should be recorded to the nearest 0.01 cm.
- 5. Measure the length of each cylinder with the vernier caliper to the nearest 0.01 cm.
- 6. Measure the length of each wire with a metric ruler to the nearest 0.5 mm.
- 7. Measure the diameter of the metal ball using the vernier caliper to the nearest 0.01 cm.
- 8. Measure the length, width, and height of the rectangular solid using the vernier caliper nearest 0.01 cm.
- 9. Determine the volume of the irregular solid using 2 methods: displacement and measurements
 - a. Displacement: Lower the irregular solid into an empty graduated cylinder. Slowly pour in a known volume of water. Read the level of the water after immersing the irregular solid. Subtract the known amount from the reading from the second to obtain the volume in cubic centimeters.
 - b. Measurement: Take measurements with the vernier caliper of the outside diameter and length and of the cavity diameter and depth. Calculate the volume of the "outside" cylinder and subtract the volume of the cavity.
- 10. Determine the volume of each stone by the displacement method, and also measure the mass of each stone.

Calculations and Results

Be sure to use appropriate significant figures in reporting answers.

1. Compute the mean of the readings for each diameter and length measured.

2. Compute and record the volume of each object measured using the mean values, paying attention to significant figures.

3. Calculate and record the density of each object **in SI units**, reporting the correct number of significant figures.

4. Compare your densities with those given in your text. Determine what the material of the object is and find the percent error between the observed and theoretical values.

5. Using Excel, or any other similar spreadsheet software, plot mass vs. volume data for the stones (plot mass in kg on the y axis, volume in m^3 on the x axis). Fit a straight line (with intercept set equal to zero) to those data, and report the average density of the stones in kg/m³.

Questions

1. In measuring the length and diameter of a cylinder, which dimensions should be measured more carefully? Why?

2. What is the volume in cubic millimeters of the largest cylinder you measured? What is the volume in liters? What is the mass in kilograms?

3. A thin circular sheet of copper has a diameter of 30.0 cm and a thickness of 1.00 mm. Find the mass of the sheet in grams (use appropriate significant figures in your answer).