EXPERIMENT 1
BASIC MEASUREMENTS, BASIC CALCULATIONS, AND CONVERSION OF UNITS

I. THEORY

The purposes of this experiment are to learn to use common instruments for measuring linear dimensions and mass, and to perform simple calculations using these measurements, including conversion of units.

Most measurements of linear dimensions are carried out in this course with the help of a one-meter stick, a two-meter stick, a vernier caliper, or a micrometer.

The micrometer is the most precise of these instruments, allowing readings to 0.001 mm. However, it is limited to measuring distances less than about 25 mm (2.5 cm).

The vernier caliper is capable of measuring lengths as large as about 12 cm. However, it is less precise than the micrometer, allowing readings to 0.1 mm (0.01 cm).

For lengths greater than 12 cm, a one-meter or two-meter stick is used. The one-meter sticks are divided into 100 cm, each of which is divided into 10 mm. These sticks allow readings to 1 mm (0.1 cm) and, for some measurements, estimates to tenths of a millimeter.

We will usually measure mass by using a triple beam balance, which has three movable standard masses. The balance allows direct readings to a precision of 0.1 g, and estimates to 0.01 g. The capacity of the balance is 610 g, but can be increased to as much as 2610 g by using additional standard masses.

The volume of a rectangular body of length L, width W, and height H is given by the formula

$$V = LWH.$$

The volume of a cylinder of diameter D and height H is given by the formula

$$V = \pi D^2 H/4 .$$

The volume of a sphere of diameter D is given by the formula

$$V = \pi D^3/6 .$$

The average density, ρ, of an object is defined by

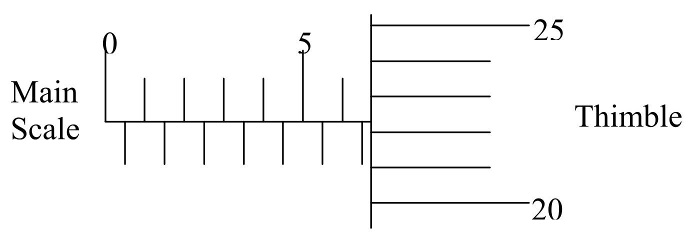
$$\rho \equiv m/V.$$

II. LABORATORY PROCEDURE

1. Use a meter stick and sliding caliper jaws to measure the length, width, and height of the inside of the laboratory equipment box. Record these values to the nearest 0.1 cm.

2. The zero correction of the micrometer is the positive or negative number that must be added to raw measurements to obtain corrected measurements. If the micrometer reads high, the zero correction is negative; if it reads low, the correction is positive. To determine the zero correction, rotate the handle of the micrometer until the jaws nearly touch each other. Then slowly turn the ratchet (the extension of the handle) until the jaws touch. Continue turning the ratchet an additional half revolution or more to generate the correct force of contact between the jaws. Now take the reading on the minor scale, which is marked in units of 0.01 mm. Estimate to the nearest 0.001 mm. Record the zero correction in mm as a positive or negative number, using the sign convention described above.

3. Slowly open the jaws of the micrometer, turning the handle about one revolution so that the minor scale reads zero and the major scale reads 0.5 mm. Open the jaws further, turning the handle a half revolution so that the minor scale reads 0.250 mm. The major scale reading is still 0.5 mm, since the 1.0 mm mark has not yet been reached. The micrometer reading is 0.750 mm (0.500 mm + 0.250 mm). Open the jaws another 0.200 mm so that the minor scale reads 0.450 mm. Even though the 1.0 mm mark on the major scale is probably visible, it has not yet been reached, so the micrometer reading is 0.950 mm (0.500 mm + 0.450 mm) not 1.450 mm. We see from this exercise that the major and minor scale readings are added together to obtain the micrometer reading, but that a major scale division is not counted until it is actually reached. In the following diagram the reading of the micrometer is 6.723 mm.

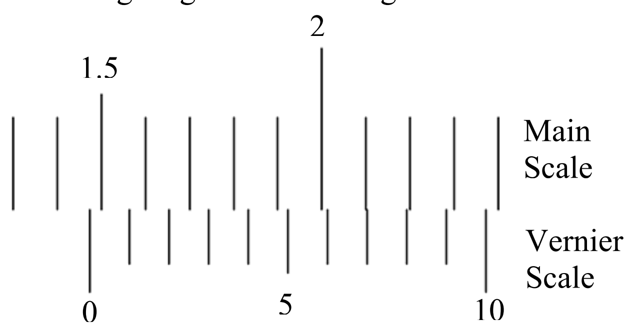


4. Use the micrometer to measure the diameter of the metal cylinder in three different places. Use the ratchet each time to obtain the correct force of contact. Estimate to the nearest 0.001 mm. Average the three readings and apply the zero correction to the average. (This is easier than applying the correction to each reading.) Convert the average value from mm to cm.

5. Record the kind of metal of which the cylinder is made. Aluminum is silver in color and low in density. Copper is red-brown. Brass is yellow. Iron is gray. Set the cylinder aside for later use.

6. Use the micrometer to make one measurement of the total thickness of ten sheets of paper, such as the paper on which the laboratory manual is printed. Estimate to the nearest 0.001 mm. Apply the zero correction.

7. Close the jaws of the vernier caliper. Notice that the zero mark of the movable vernier scale lines up with the zero mark of the main scale. If it does not line up inform your instructor. Also note that ten divisions of the vernier scale are equal to nine divisions of the main scale. Fix your attention on the 5 mark of the vernier scale. Using the thumbwheel, slowly open the jaws until the 5 mark of the vernier scale lines up with the next mark of the main scale. The zero mark of the vernier scale should be halfway between 0.0 and 0.1 cm on the main scale. The caliper now reads 0.05 cm. We see from this exercise that centimeters and tenths of centimeters are read on the main scale, at that point where the zero mark of the vernier scale is located. Hundredths of centimeters are read by finding that mark on the vernier scale that most nearly lines up with a mark on the main scale. In the following diagram the reading of the vernier caliper is 1.47 cm.



8. Use the vernier caliper to take two measurements of the height of the metal cylinder, reading the caliper to the nearest 0.01 cm. Average the two values. Set the cylinder aside for later use.

9. Use the vernier caliper to take one reading of the diameter of the glass marble, reading the caliper to the nearest 0.01 cm. Set the marble aside for later use.

10. Slide the three standard masses of the triple beam balance to the far left position. Observe whether the mark on the right end of the beam structure lines up with the zero mark on the frame. If not, use the adjusting knob at the left end of the balance to “zero” the balance.

11. Use the balance to measure the mass of the metal cylinder to the nearest 0.01 g.

12. Measure the mass of the glass marble to the nearest 0.01 g.

III. CALCULATIONS

Reminder: You should use scientific notation to express any numerical result less than 10^{-3} or greater than 10^{4} or if necessary to indicate significant figures.

1. Calculate the volume of the inside of the laboratory equipment box in cm^3. Convert the volume to mm^3.

2. Calculate the volume of the metal cylinder in cm^3.

3. Calculate the density of the metal cylinder in g/cm^3.

4. Calculate the percent error in the density of the metal cylinder, using the following table of standard values:

metal	aluminum	brass	copper	iron
density (g/cm^3)	2.70	8.44	8.93	7.86

5. Estimate possible absolute errors in your measurements of the diameter, the height and the mass of the metal cylinder. Give some justification for these estimates. Use the rules of error propagation to calculate the possible relative error in the density of the cylinder. Comment on this result. How does the possible relative error compare to the percent error? What does this imply about your measured density?

6. Calculate the volume of the glass marble in cm^3.

7. Calculate the density of the glass marble in g/cm^3. One textbook lists the density of common glass as ranging from 2.4 to 2.8 g/cm^3. Does your value fall within this range?

8. Estimate possible absolute errors in your measurements of the diameter and the mass of the marble. Give some justification for these estimates. Use the rules of error propagation to find the possible ***absolute*** error in the density of your marble. What is the range of values for the density of your marble? Comment on this result.

9. Convert the density of your marble into kg/m^3.

10. How many marbles could fit into the equipment box? Consider 11% of the volume of the box to consist of the empty space between marbles, so that only 89% of the box volume actually contains glass. Calculate the mass of this many marbles in kilograms.

11. Calculate the expected thickness of one ream (500 sheets) of paper in mm. Convert this thickness to inches. Does your answer seam reasonable? (You have probably all seen a ream of paper for a computer printer. If not, a textbook which has pages numbered 1-1000 is made up of 500 sheets of paper.)