Measurements

Theory

When a physical quantity is measured, the result of the measurement is expressed by means of a number that represents its numerical size and a unit in terms of which the quantity is measured. The *fundamental units* are the units in which the fundamental quantities of length, mass, and time are measured. These fundamental quantities can be expressed in either the English system using the foot (ft), pound (lb), and second (s) or the SI system using the meter (m), kilogram (kg), and second (s). The units that are derived from the fundamental units on the basis of established physical relationships or laws are called *derived units.*

To make an accurate determination of a physical quantity such as the gravitational constant, the coefficient of expansion, or the length of an object, many readings must be taken and averaged. The agreement of these values with one another is a measure of the accuracy with which the quantity has been determined. In elementary laboratory work, time does not permit intensive research, so results vary from each other and from handbook values. An essential part of reporting an experiment is the indication of this variation or error and a statement of possible sources of error.

The *error* is the difference between the expected result (or handbook value) and the experimental result. For measurements such as those of length where there is no expected value the probable error may be computed by estimating the error involved in each measuring process. The probable error should never be expressed with more than one significant figure, and the experimental value should never be expressed more accurately than indicated by the probable error.

The percent error is defined as the error, the absolute value of the difference between the expected value and the experimental value, divided by the expected value and multiplied by 100%. Or

$$\%\ \text{error} = \frac{|\text{error}|}{\text{expected value}} \times 100\% = \frac{|\text{expected value} - \text{experimental value}|}{\text{expected value}} \times 100\%$$

As an example let us say that an experimental value is determined to be 4.34 and the handbook value (expected value) is 4.32, the error is

$$\text{error} = |4.32 - 4.34| = 0.02$$

Purpose

An integral part of any laboratory procedure is the ability to make accurate measurements. In this experiment, you are asked to investigate the process of measurement and to determine the accuracy of various measuring instruments. In addition, you will be introduced to the measurement of the three fundamental quantities—length, mass, and time.

Apparatus

Card, meterstick, English-SI ruler, Vernier caliper, micrometer, set of density metal cylinders, balance and masses, several wooden blocks of various sizes, and several small spheres.

Source: Puri
Modified by Zober and Zober

And the % error is

$$\% \text{ error} = \frac{|\text{error}|}{\text{expected value}} \times 100\% = \frac{0.02}{4.32} \times 100\% = 0.463\%$$

Which should be rounded to 0.5%.

When many readings are taken of the same quantity, the average deviation of the readings from the mean is a good estimate of the probable error in the experiment. For example, suppose that the length of a sample is measured with the following results:

Reading	Length (cm)	Absolute Deviation from the Mean
1	3.54	0.01
2	3.52	0.01
3	3.53	0.00
4	3.55	0.02
5	3.51	0.02
sum	17.65	0.06

$$\text{Mean value for the length} = \frac{17.65}{5} = 3.53$$

The average deviation is $\frac{0.06}{5} = 0.012 = 0.01$, keeping only one significant figure. This value of 0.01 is the probable error in the determination of the length of the object, and should be reported as:

$$\text{Length} = 3.53 \text{ cm} \pm 0.01 \text{ cm}$$

This means that any future readings will most likely lie between 3.52 and 3.54 cm.

In making measurements, figures obtained from the measuring instruments are called significant figures. In a measured quantity, all figures are considered significant except those used to locate the decimal point. For example, you are asked to measure the width of a small study table. You report an answer of 1.65 m. In this case all three figures are significant. Suppose you are asked to calculate the distance between your home and school and your answer is 3 200 m. In this case, only the 3 and the 2 are significant. Suppose further that it is necessary for you to measure the length of your laboratory notebook using a stick calibrated in centimeters only. It measures a little longer than 28 cm but less than 29 cm and seems to be about 5 tenths of the way from 28 to 29, or 28.5 cm long. Then the same book is measured with a ruler calibrated in centimeters and tenths of centimeters. The new measurement is 28.45 cm. The first measurement (28.5 cm) has three significant figures; the second (28.45 cm) has four significant figures. The difference between these two measurements is the degree of precision with which they have been made.

In this experiment we will make measurements on a set of blocks and it will be important to be as accurate as possible. We will first measure a block in inches and then in cgs-metric unit of the centimeter. From the information, called *data*, that we gather we will determine an experimental conversion factor.

In physics we say that one measurement is no measurement. If you measure an object and commit a measuring error, you have no way of knowing that your work is incorrect. Making a second and third measurement makes a measuring error unlikely. For this reason we will make a set of three measurements or determinations or trials in most of our experimental work. In this experiment we will make three sets of measurements, or, as we say, three trials.

Materials have two sets of properties, chemical and physical. Chemical properties deal with how substances react chemically. Does it burn? Will it support combustion? How does it react with acids or bases? Physical properties deal with properties we usually determine through our senses. What is the color of the substance? What is its odor? What is its taste? What is the melting point? What is the boiling point? What is the phase under normal conditions? There are many others we will learn about in our study of physics.

One of the more important of the physical properties is density. In dealing with the SI system we refer to this property as *mass density*. Simply stated, mass density, ρ, is defined as the mass of a material divided by its volume, or, mathematically

$$\rho = \frac{m}{V} \tag{1}$$

In dealing with small objects it is convenient to use the cgs-metric where m is mass in grams, g, V is the volume in cm^3, and ρ is the mass density in $\frac{g}{cm^3}$.

To calculate the volume of a cylinder we use the formula

$$V = \pi R^2 L \tag{2}$$

Where L is length of the cylinder and R is radius.

The volume of a sphere is given by

$$V = \frac{4}{3}\pi R^3 \tag{3}$$

LEARNING OBJECTIVES

After completing the experiment you should be able to do the following:

1. Increase the precision of your measurements by the correct use of the Vernier caliper and the micrometer.
2. Explain the difference between the fixed scale and the movable scale of the Vernier caliper.
3. Calculate the volume and the density of an object.
4. Be able to express you answer in significant figures.
5. In determining the volume of a cylinder you should be able to explain what dimension needs to be the most "precise".
6. Be able to calculate absolute error and percent error.

PROCEDURE

PART A.

1. Using a meterstick, take 10 measurements, in centimeters, of the length of a card issued to you. Determine the mean value, average deviation, and the % deviation. In the same way, measure the width of the card. From these measurements calculate the area of the card and indicate the reliability of your result quantitatively.

2. Repeat the length measurement described above, this time making the measurements in inches. From the two measurements of length, calculate the ratio $\frac{cm}{in}$. Determine the reliability of the result. Calculate the % error in your result, assuming that the correct value of the ratio is 2.540 $\frac{cm}{in}$.

PART B.

3. Choose a block. This block is your first choice and will be treated as such in future reference.

4. Using the English side of the ruler, carefully and as accurately as possible, measure the dimensions of the block. Convert any fractional value into a decimal. Record these measurements in your data. Do a second and a third trial on the block and record.

5. Using the metric side of the ruler, repeat the above procedure measuring the block in centimeters and record these dimensions in your data.

6. Find the average length, width, and height of the block for both systems. Use these average values and calculate the volume of the block in cubic centimeters and cubic inches.

7. Divide the average volume of the block in cubic centimeters by the volume in cubic inches. This value is your experimental conversion factor for cubic centimeters and cubic inches. The accepted value is 16.39 $\frac{cm^3}{in^3}$. How does this value compare with your experimental value? Find the error and % error.

8. Take a second block and make the same measurements and calculations you did for the first block. Record these values.

Part C.

9. Pick one of the metal cylinders. After instruction of the use of the Vernier caliper, measure the length and diameter of the cylinder. Make 3 trials and record the data.

10. Use the average radius and length and calculate the volume of the cylinder. Record.

11. Mass the cylinder on a balance. Record your mass in grams.

12. Calculate the mass density of the cylinder, R. Compare your experimental mass density to accepted values in the density table in the appendix of your lab manual.

13. Repeat the above procedures for a second cylinder.

Part D.

14. After instruction on the use of the micrometer, measure the diameter of one of the spheres.

15. Mass the sphere and record this mass.

16. Calculate the mass density of the sphere. Compare your experimental mass density to accepted values in the density table in the appendix of your lab manual.

17. Repeat the above procedures with a second sphere.

Questions

1. In measuring the dimensions of a cylinder for calculating the volume, which dimension needs to be more precise?

2. If you make a 1% error in the measurement of either the diameter or the length of a cylinder, what is the error in the volume?

3. How is the surface area of a sphere related to its volume?

4. Explain how you would measure the density of an irregular solid.

5. Can you accurately measure the volume of a material that floats? How would you measure the volume?

Measurements

Name: ______________________ Date: ______________________

Part A.

Trial	Length L	Width W	Length L	Width W
No.	cm	cm	in	in
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Length:

Mean value ______________ cm Mean value ______________ in

Average deviation ______________ cm Average deviation ______________ in

% Deviation ______________ % % Deviation ______________ %

Width:

Mean value ______________ cm Mean value ______________ in

Average deviation ______________ cm Average deviation ______________ in

% Deviation ______________ % % Deviation ______________ %

Area:

Area ______________ cm^2 Area ______________ in^2

Experimental conversion factor ______________ $\frac{cm}{in}$

Accepted value 2.540 $\frac{cm}{in}$

Error ______________ $\frac{cm}{in}$

% Error ______________ %

Part B.

Block 1

Trial	Length L	Width W	Height H	Length L	Width W	Height H
No.	cm	cm	cm	in	in	in
1						
2						
3						

Average volume ____________ cm^3

Average volume ____________ in^3

Experimental conversion factor ____________ $\frac{cm^3}{in^3}$

Accepted value 16.39 $\frac{cm^3}{in^3}$

Error ____________ $\frac{cm^3}{in^3}$

% Error ____________ %

BLOCK 2

Trial	Length L	Width W	Height H	Length L	Width W	Height H
No.	cm	cm	cm	in	in	in
1						
2						
3						

Average volume ______________ cm^3

Average volume ______________ in^3

Experimental conversion factor ______________ $\frac{cm^3}{in^3}$

Accepted value 16.39 $\frac{cm^3}{in^3}$

Error ______________ $\frac{cm^3}{in^3}$

% Error ______________ %

Part C.

Cylinder 1 Material ______________

Trial	Length L	Diameter D	Radius R
No.	cm	cm	cm
1			
2			
3			

Volume ______________ cm^3

Mass ______________ g

Experimental mass density ______________ $\frac{g}{cm^3}$

Accepted mass density ______________ $\frac{g}{cm^3}$

Error ______________ $\frac{g}{cm^3}$

% Error ______________ %

CYLINDER 2 MATERIAL ______________

Trial	Length L	Diameter D	Radius R
No.	cm	cm	cm
1			
2			
3			

Volume ______________ cm^3

Mass ______________ g

Experimental mass density ______________ $\frac{g}{cm^3}$

Accepted mass density ______________ $\frac{g}{cm^3}$

Error ______________ $\frac{g}{cm^3}$

% Error ______________ %

PART D.

SPHERE 1 MATERIAL ______________

Trial	Length L	Diameter D	Radius R
No.	cm	cm	cm
1			
2			
3			

Volume ______________ cm^3

Mass ______________ g

Experimental mass density ______________ $\frac{g}{cm^3}$

Accepted mass density ______________ $\frac{g}{cm^3}$

Error ______________ $\frac{g}{cm^3}$

% Error ______________ %

SPHERE 2 MATERIAL ____________

Trial	Length L	Diameter D	Radius R
No.	cm	cm	cm
1			
2			
3			

Volume ____________ cm^3

Mass ____________ g

Experimental mass density ____________ $\frac{g}{cm^3}$

Accepted mass density ____________ $\frac{g}{cm^3}$

Error ____________ $\frac{g}{cm^3}$

% Error ____________ %