

Experiment 1

MEASUREMENT

Fall 2026 _V2

EQUIPMENT

3 discs of different diameters	Computer Software: Sphere Volume
3 spheres of different diameters	Circle Area
3 unknown masses	Calculator
1 set of standard masses	Percent Error Program
1 metric ruler	1 250g spring scale
1 vernier caliper	1 stopwatch
1 electronic balance	1 wristwatch or wall clock
1 reflex strip	

INTRODUCTION

The purpose of this experiment is to become familiar with methods of measurement and error. In the study of physical objects it is very important to be able to systematically measure the quantities of length, mass, and time. In this experiment you will investigate methods of making these measurements. Then you will use the computer to calculate the area and volume of several objects.

Although you are probably more familiar with measuring things in units of pounds, feet, miles, etc., the international community of scientists have adopted a system using kilograms, meters, and for time, seconds. These units form the basis of the SI (Système International) or the MKS (meter, kilogram, second) measurement system. These are metric units. One advantage of the metric system is that it is based on the decimal system. One tenth of a meter is called a decimeter, one hundredth of a meter is called a centimeter, and one thousandth of a meter is called a millimeter. Similarly, 1000 meters is called a kilometer (about 0.62 miles). You will find more information about the metric system and conversions in the appendix.

Every measurement that you make is a comparison. The characteristic you wish to quantify must be measured in comparison to a standard. The first international standard of length was a bar called *The Standard Meter* kept in the *Bureau of Weights and Measures* in Paris. Historically, the meter was intended to be a convenient fraction (1/10,000,000) of the distance between the North Pole and the equator traveling along a line through Paris. There are copies of this standard meter in the laboratory and you will use these as your first technique for measuring length.

The standard unit for mass is the kilogram. *You will use scales that measure mass in grams.* Mass is a property of an object that is related to the gravitational force acting on it, in other words, its weight. **Mass and weight are not the same, and should not be confused.** Mass can also be considered a measure of an object's inertia or resistance to change in motion. Mass is an important property of an object as it can be used in determining the acceleration and momentum of the object. There is, of course, a standard kilogram mass in the Bureau of Weights and Measures. Copies are available in the laboratory.

The standard unit of time is the second, and it was defined as 1/86,400 of a mean solar day. It is a bit difficult to keep a copy of the standard clock around since the standard clock is based on the vibrations of a cesium atom. However, there are electronic stopwatches available for your use in the laboratory.

Measurement of Length

There are a number of different ways to measure length. Some you are familiar with, such as simple estimation, the use of rulers, tape measures, and such. Others you may not be so familiar with, such as the use of micrometers, calipers, and electronic rangefinders. The method chosen to make a linear measurement depends upon the accuracy desired and the distance involved. You can easily estimate the distance from your seat to the door, say three or four meters, but it would not probably be so easy to estimate the diameter of a coin. In the first instance it would be unnecessary to use a ruler graduated in tenths of a centimeter to find the distance, while in the second case it may be very necessary to use calipers graduated in tenths of a millimeter. In this experiment you will try different techniques on several small objects to discover the relative merits of each.

To measure the length of an object, place the object on the ruler exactly on a millimeter mark. Then determine the length by measuring the difference between the two scale positions. That is, the length of the object is the difference in the right and left scale readings. Note that it may be difficult to accurately place the object on the ruler so that you are measuring the exact length. For this reason, it is wise to make several measurements of the length and average the results.

A more precise method of measuring length is achieved by the use of a caliper. The object whose length is to be measured is placed between the two jaws of the caliper and held lightly, but firmly. The caliper you will use is designed to measure tenths or hundredths of a main scale division. In this way measurements can be made to tenths of a millimeter while measurements with your ruler can be accurate only to within an estimated 1/2 millimeter.

Measurement of Mass

Mass is usually measured on some type of scale. This scale may be mechanical or electronic. In either case, the gravitational force on the object causes a displacement of the scale mechanism that is then measured. In this laboratory you will use a simple spring scale, then a triple beam balance then a digital balance to find the masses of some objects.

To use the spring scale, simply attach the object whose mass is to be measured to the spring hook and read the value adjacent to the scale pointer. This is a fast but not particularly precise method. A better method is measurement by the triple beam balance. Here the mass to be measured is placed on the weight pan and the sliding masses on the balance beams are adjusted to give a zero reading at the pointer. The mass of the object is then read as the sum of the values at which the sliding masses are aligned. The most accurate method we will use is the electronic balance. Simply place the object on the pan and read the measurement.

Measurement of Time

Time is the easiest physical quantity to measure. Most everyone wears a wristwatch these days, and some hand calculators have a clock function. In laboratory exercises you may sometimes keep track of time with wrist watches or wall clocks. However, for more accurate measurements you will use a stopwatch. This timepiece measures time to a hundredth of a second and will serve as the time standard in this experiment.

Calculation of Area

It is quite often necessary to calculate the area of an object. To help you make such mathematical calculations you are going to use a computer program.

Remember that *the area of a rectangular surface is equal to its length times its width*, so that the surface area of an object 1-cm high and 1 cm wide is 1 cm² (one square centimeter). An object 2-cm high and 4 cm wide would have an area of 8 cm² (eight square centimeters).

The area of a circle is equal to pi (π) times the radius of the circle squared (πr²). Since the radius is one half the diameter, you can remember that the area of a circle is equal to pi times one half the diameter squared. In one part of the experiment you will calculate the surface areas of several discs whose diameters you have measured.

Calculation of Volume

Sometimes it is necessary to calculate the volume of an object. For instance, *the volume of a rectangular object is equal to its length times its width times its height or L*W*H*. For example, an object 2m high, 3m wide, and 4m deep has a volume of 24m³ (24 cubic meters).

The objects that we will measure in this lab are more common than cubes and rectangles. They are spheres. Thus, it is necessary to know how to calculate the volume of a sphere. **The formula for the volume of a sphere is:**

$$\text{volume} = 4/3\pi R^3$$

where R is the radius of a sphere.

Since R = D/2, where D is the diameter of the sphere, we can substitute D/2 in place of R in the equation above which yields

$$\text{Volume of sphere} = 1/6\pi D^3$$

Use the computer and the appropriate program to make this calculation. By using the correct program, it is only necessary to enter the diameter of the object that you have measured. From this, the volume of the object will be determined. In this way, you are able to complete the same calculations for various objects very quickly. This illustrates that computers are very useful in doing repetitive computations.

Calculation of Error

It is important to recognize that any measurement you make is subject to error regardless of the care with which you make the measurement. To indicate how precise or reliable a given measurement is, it is often convenient to determine the percentage error. The percent error can be calculated using the following formula:

$$\text{Percent error} = \frac{|T - M|}{T} \times 100$$

Where T is the true value and M is the measured value.

Whenever the true value of the quantity is known, you can calculate percent error and determine the accuracy of your experiments. In some experiments this will be possible, in others it will not. But, whenever you are given the correct value for a quantity, you should calculate the percent error of your measurement. The sign of the percent error is not significant. Record the absolute value (% error without a sign) on your data sheet. Make certain you understand the number of significant figures to report. See Appendix F.

PROCEDURE

Discs & spheres are in plastic bag.

A. Measurement of Length

1. Make a best guess estimate of the diameters of 3 different discs. Your answer should be in metric units. Since you may not be familiar with metric sizes, you may use a metric ruler for reference, but do not place the ruler on the object yet. Record your best guess to the 1/2 cm in the space provided in the data table.
2. Now use the ruler to measure the diameters of the 3 disks. The ruler can measure length to 1 mm (0.1 cm). Record the measurements on the data chart.
3. Repeat the measurements using a caliper. The caliper can measure lengths to a resolution of 0.01 mm or 0.001cm. Record the results.
4. Use the ERROR program to calculate the percent error of your estimates and the measurements made with the ruler. **Use the caliper measurements as the true values.** Record your findings on the data table.
5. Measure the diameters of 3 different spheres by repeating steps 1 through 4. Record the results on the data table.

B. Measurement of Mass

6. Obtain 3 objects of unknown mass from your laboratory instructor. Estimate the mass of each of these objects by holding the object in one hand and some known mass, from the standard mass set, in the other hand. Record your estimates.
7. Now measure the unknown masses using the spring scale. Record the results.
8. Repeat the measurements with the triple beam balance and record the results. Note the 100g and 500g scales have notches for

the sliding masses. The sliding masses must be in a notch to get a correct reading.

9. Repeat using the electronic balance.
10. Use the ERROR program to calculate the percent error of your estimate, the spring measurement, and triple beam balance measurement. **Use the electronic balance as the true value.** Record the results.

C. Measurement of Time

11. Estimate a 30-second interval by counting (you can tap your foot or use your heartbeat to establish rhythm). Your lab partner should time you in this exercise with the stopwatch. Help your partner by giving him or her start and stop commands. Record your estimates.
12. Measure a 30-second interval by watching the wall clock or the second hand on your wristwatch. Again give your partner start and stop commands so they can time you with the stopwatch. Record the results.
13. Use the reflex testing strip to find your time to start and stop the stopwatch. Do you think you can actually measure time to $\frac{1}{100}$ of a second (i.e., 0.01 s) using a stop watch?

(See Question # 6)

14. Use the %ERROR program to calculate the error of your estimates and clock watching. **Remember that the stopwatch is your true value.** Record the results.

D. Calculation of Area and Volume

15. Run the CIRCLE AREA and SPHERE VOLUME programs to find the area of each disk and the volume of each sphere. Record the results.

Experiment 1

DATA SHEET

Name: _____

Section: _____

A. Measurement of Length

Object	Estimated Diameter (cm)	Diameter by Ruler (cm)	Diameter by Caliper (cm) (TRUE)	% Error of Estimate	% Error of Ruler Measurement
disc 1					
disc 2					
disc 3					
sphere 1					
sphere 2					
sphere 3					

B. Measurement of Mass

Object	Estimated Mass (g)	Mass by Spring Scale (g)	Mass by Triple Beam Balance(g)	Mass by Electronic Balance (g) [True]	% Error of Estimate	% Error of Spring Scale Measurement	% Error of Triple Beam
unknown 1							
unknown 2							
unknown 3							

C. Measurement of Time

Estimate of Time	Stopwatch Time (s) [TRUE]	Time Measured On Clock (s)	Stopwatch Time (s) [True]	% Error of Estimated Time	% Error of Watched Time	Reflex Time (s)
30 sec		30 sec				

Experiment 1

DATA SHEET

D. Calculation of Area and Volume

Object	Calculated Area (cm ²)
disc 1	
disc 2	
disc 3	

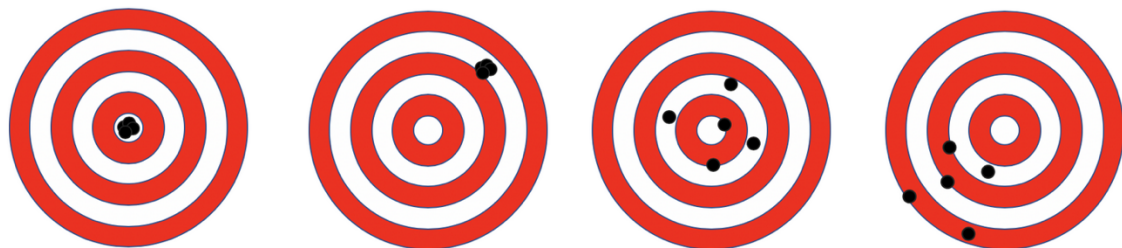
Object	Calculated Volume (cm ³)
sphere 1	
sphere 2	
sphere 3	

POST LAB QUESTIONS

1. “**Accuracy** is how close a measurement is to the true or accepted value. **Precision** is how close repeated measurements are to each other, no matter if they are close to the true value.”

a) Properly label the figures below - *It is assumed that the center of the bullseye is what you are aiming for.*

Your options are: 1) Accurate but not precise 2) Not accurate, not precise 3) accurate & precise 4) precise but not accurate. **You are to explain your answers below.**



2. Which system of measurement do you think is better? The metric system or the ‘English’ system? Explain your answer. *Interesting factoid- The system used in the U.S. is called “U.S. Customary Units”.*
3. What is the standard unit for length, mass, weight and time in the MKS metric system? What is the standard unit for length, mass, weight and time in the ‘English’ system? Why are units important in general and in particular when reporting the result of a measurement?

4. What is the purpose of using percent error? Does percent error have units? Why not just say error is plus or minus some number including units.

5. Complete the following calculations using the explanation of significant figures given below.

- When **multiplying and dividing** several quantities, the number of significant figures in the final answer is the same as the number of significant figures in the quantity with the least amount of significant figures that is being multiplied.
- When **adding and subtracting** several quantities, the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum.

Given: $x = 12.24$ $y = 5400$ $z = 11.572$

Determine: $x * y * z = \underline{\hspace{2cm}}$

$x + z = \underline{\hspace{2cm}}$

6. The two statements below were given by 'Google' in reply to the question '**Minimum time resolution measurable by humans**'.

Humans can visually resolve changes in time down to about **10 to 13 milliseconds** (roughly 75 to 90 images per second),

Trained Limits: Fighter pilots and fast-paced video gamers can sometimes spot changes closer to 13 milliseconds, while **average people max out near 50 to 100 milliseconds** for standard flicker fusion.

Consider the results of your reflex time measurement and the two statements above, answer the following:

What precision, in fractions of seconds, can you claim for an interval timed by a stopwatch, e.g., for a 40-yard dash? **Explain your answer** using some of the times above.

Show any work (such as unit conversions)

1st Step- Convert milliseconds above to seconds.

2nd Step- Compare these times to the digits of a stop watch