Introduction to Measurement

Mass, Length, and Volume

Introduction

Much of what we know about the physical world has been obtained from measurements made in the laboratory. Skill is required to design experiments so that careful measurements can be made. Skill is also needed to use lab equipment correctly so that errors can be minimized. At the same time, it is important to understand the limitations of scientific measurements.

Concepts

- Measurement
- Accuracy and precision
- Significant figures
- Experimental error

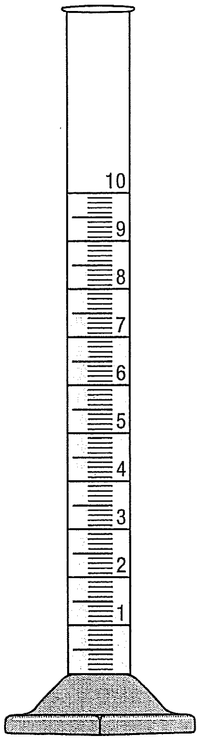
Background

Experimental observations often include measurements of mass, length, volume, temperature, and time. There are three parts to any *measurement:*

- its numerical value
- the unit of measurement that denotes the scale
- an estimate of the uncertainty of the measurement.

The numerical value of a laboratory measurement should always be recorded with the proper number of *significant figures*. The number of significant figures depends on the instrument or measuring device used and is equal to the digits definitely known from the scale divisions marked on the instrument plus one estimated or "doubtful" digit. The last, estimated, digit represents the uncertainty in the measurement and indicates the precision of the instrument.

Measurements made with rulers and graduated cylinders should always be estimated to one place beyond the smallest scale division that is marked. If the smallest scale division on a ruler is centimeters, measurements of length should be estimated to the nearest 0.1 cm. If a ruler is marked in millimeters, readings are usually estimated to the nearest 0.2 or 0.5 mm, depending on the observer. The same reasoning applies to volume measurements made using a graduated cylinder. A 10-mL graduated cylinder has major scale divisions every 1 mL and minor scale divisions every 0.1 mL. It is therefore possible to "read" the volume of a liquid in a 10-mL graduated cylinder to the nearest 0.02 or 0.05 mL. Three observers might estimate the volume of liquid in the 10-mL graduated cylinder shown at the right as 8.32, 8.30, or 8.33 mL. These are all valid readings. It would NOT be correct to record this volume of liquid as simply 8.3 mL. Likewise, a reading of 8.325 mL would be too precise.



Some instruments, such as electronic balances, give a direct reading—there are no obvious or marked scale divisions. This does NOT mean that there is no uncertainty in an electronic balance measurement; it means that the estimation has been carried out internally (by electronic means) and the result is being reported digitally. There is still uncertainty in the last digit. On an electronic centigram balance, for example, the mass of a rubber stopper might be measured as 5.67 g. If three observers measured the mass of the same rubber stopper, they might obtain readings of 5.65, 5.67, and 5.68 g. The uncertainty of an electronic balance measurement is usually one unit in the smallest scale division that is reported—on a centigram balance this would be ±0.01 g.

Accuracy and precision are two different ways to describe the error associated with measurement. *Accuracy* describes how "correct" a measured or calculated value is, that is, how close the measured value is to an actual or accepted value. The only way to determine the accuracy of an experimental measurement is to compare it to a "true" value—if one is known! *Precision* describes the closeness with which several measurements of the same quantity agree. The precision of a measurement is limited by the uncertainty of the measuring device. Uncertainty is often represented by the symbol ± ("plus or minus"), followed by an amount. Thus, if the measured length of an object is 24.72 cm and the estimated uncertainty is 0.05 cm, the length would be reported as 24.72 ±0.05 cm.

Variations among measured results that do not result from carelessness, mistakes, or incorrect procedure are called *experimental errors*. Experimental error is unavoidable. The magnitude and sources of experimental error should always be considered when evaluating the results of an experiment.

Experiment Overview

The purpose of this activity is to make measurements using the metric system, to learn the meaning of significant figures in the measurements, and to compare the accuracy and precision of laboratory measurements.

Pre-Lab Questions

1. How does the concept of significant figures relate to uncertainty in measurement?
2. A pipet is a type of specialized lab glassware that is used to deliver a specified volume of liquid. A 5-mL pipet has major scale divisions marked for every milliliter and minor scale divisions marked for every 0.1 mL. How would you estimate the uncertainty in volume measurements made using this pipet? Would it be proper to report that the pipet was used to deliver 3.2 mL of liquid? Explain.
3. A stack of ten musical compact disks is 1.15 cm tall. What is the average thickness of one disk? To the nearest whole number, how many disks will be in a stack that is 5 cm tall?

Materials

Balance, centigram (0.01 g) or milligram (0.001 g) precision
Beaker, 50-mL
Graduated cylinders, 10-, 25-, 100-, 500-, and 1000-mL
Metric ruler, marked in millimeters
Nickels, 5–6
Pennies, 5–10 (at least one of which was minted in 1982 or before)
Pipet, Beral-type
Water

Safety Precautions

The materials in this lab activity are considered nonhazardous. Always wear chemical splash goggles when working in the laboratory with glassware, heat, or chemicals.

Procedure

Part A. Volume Measurements

There are five graduated cylinders, each labeled and each containing a specific quantity of liquid to which some food coloring has been added to make the volume easier to read.

1. Record the capacity and the major and minor scale divisions of each graduated cylinder in Data Table A.

2. Measure the volume of liquid in each cylinder and record the results in Data Table A. Remember to include the units and the correct number of significant figures.

3. Estimate the "uncertainty" involved in each volume measurement and enter the value in Data Table A.

Part B. Comparing Volume Measurements

4. Use tap water to fill a 50-mL beaker to the 20-mL mark. Use a Beral-type pipet to adjust the water level until the bottom of the meniscus is lined up as precisely as possible with the 20-mL line.

5. Pour the water from the beaker into a clean, 25-mL graduated cylinder. Measure the volume of liquid in the graduated cylinder and record the result in Data Table B. Remember to include the units and the correct number of significant figures.

6. Transfer the liquid from the 25-mL graduated cylinder to a clean, 100-mL graduated cylinder and again measure its volume. Record the result in Data Table B. Discard the water into the sink.

7. Repeat steps 4–6 two more times for a total of three independent sets of volume measurements. Dry the beaker and graduated cylinders between trials. Record all results in Data Table B.

8. Calculate the average (mean) volume of water in both the 25- and 100-mL graduated cylinders for the three trials. Enter the results in Data Table B.

Part C. Measuring the Diameter and Thickness of a Coin

Enter all data in Data Table C. Report each measurement or calculation to the proper number of significant figures. Don't forget the units.

9. Use a metric ruler to measure the diameter of a penny. Record the measurement in both centimeters (cm) and millimeters (mm).
10. Estimate and record the uncertainty involved in this measurement of length.
11. Make a stack of pennies that is as close as possible to 10 millimeters in height. Count the number of pennies used to make this 10-mm stack and record the result.
12. Measure and record the precise height of the stack of pennies in both centimeters and millimeters. Divide the measured height of the stack of pennies by the number of pennies to calculate the "average thickness" of a penny in millimeters. Record the result.
13. Measure the thickness (in millimeters) of one penny chosen at random from your stack and enter this value in Data Table C.
14. Repeat steps 9–12 using nickels instead of pennies.

Part D. Mass Measurements

15. Obtain five pennies and record the year in which each penny was minted. Measure the mass of each penny individually using a centigram or milligram balance. Record the results in Data Table D. *Note:* Make sure that at least one of the pennies was minted in 1982 or before.

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Introduction to Measurement

Data Table A. *Volume Measurements*

Graduated Cylinder	Capacity	Major Scale Divisions	Minor Scale Divisions	Volume of Liquid	Estimated Uncertainty
A					
B					
C					
D					
E					

Data Table B. *Comparing Volume Measurements*

	Measured Volume of “20 mL” of Water	
Trial	25-mL Graduated Cylinder	100-mL Graduated Cylinder
1		
2		
3		
Average		

Data Table C. *Measuring the Diameter and Thickness of a Coin*

	Diameter of Coin		Number of Coins in 10-mm Stack	Measured Thickness of Stack	Average Thickness of Coin	Measured Thickness of Single Coin
Penny	Centimeters					
	Millimeters					
	Uncertainty					
Nickel	Centimeters					
	Millimeters					
	Uncertainty					

Data Table D. *Mass Measurements*

Penny	Year Minted	Mass
1		
2		
3		
4		
5		

Post-Lab Questions *(Use a separate sheet of paper to answer the following questions.)*

1. What is the relationship between the scale divisions marked on the graduated cylinders in Part A and the estimated uncertainty in volume measurements?
2. Which graduated cylinder(s) gave the most precise volume measurement? Does the *number* of significant figures allowed for each volume measurement in Part A reflect the precision of the graduated cylinders?
3. It is common to get different volume readings for each container in Part B. What explanation can you offer for an apparent decrease or increase in volume?
4. For both the 25- and 100-mL graduated cylinder measurements in Part B, calculate the *deviation* of each measured volume from the average. The deviation is equal to the absolute value of the difference between each measured volume and the average as follows:

$$\text{deviation} = |\text{measured volume} - \text{average volume}|$$

5. Calculate the *average deviation* for both the 25- and 100-mL graduated cylinder measurements in Part B. The average deviation is equal to the sum of the individual deviations from the average divided by the number of measurements. Report the volume measurements for both cylinders in the following form:

$$\text{average} \pm \text{average deviation}$$

6. The average deviation shows how precise a series of measurements are. Compare the precision of the volume measurements obtained using the 25- and 100-mL graduated cylinders. Do these values really represent the precision of the graduated cylinders themselves?
7. Assume that the average volume found using the 25-mL graduated cylinder in Part B is the "true" or accepted value of the volume. Calculate the *percent error* for the average volume of water measured using the 100-mL graduated cylinder. The percent error is calculated as follows:

$$\text{percent error} = \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}} \times 100\%$$

8. Does percent error measure accuracy or precision? Explain.

9. Are the average thickness and measured thickness of the coins measured in Part C the same? What factors might explain the difference? Which method do you think gives a better estimate of the true thickness of a coin?
10. Compare the masses of the pennies measured in Part D. Are all of the masses the same, *within the limits of uncertainty in the balance measurement?* Are there apparent differences based on when the pennies were minted?
11. How does the mass of a penny minted in 1982 or before compare with the mass of newer pennies. Try to explain the difference.