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P.O. Box 219 • Batavia, IL 60510
(800) 452-1261 • Fax (866) 452-1436
www.flinnsci.com • E-mail: flinn@flinnsci.com

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Measurement Challenge

Measurement Lab Activities

Introduction

Take the measurement challenge! Accurately estimate the length, width, and height of a small plastic block and calculate the block's volume. Then predict the mass of the block—without a balance—by using the block's known density.

Concepts

- Measurement
- Estimations and certainty
- Significant figures
- Volume, mass and density

Background

All measurements involve some degree of error or estimation. The measurements are based on the fact that the human eye can estimate to one-tenth of the smallest mark shown on a measuring instrument. Therefore, a ruler with only 1-cm increments shown can provide measurements that are estimated to 0.1 cm, while a ruler with 0.1-cm increments shown can provide measurements that are estimated to 0.01 cm.

In this activity, the first goal is to determine the volume of a plastic block. The volume of any regular solid can be calculated using Equation 1. The length, width, and height must be estimated using a reliable measuring instrument.

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Height} \qquad \textit{Equation 1}$$

Once the solid's volume has been calculated, the mass can be predicted using the known density value of the solid. To predict the mass, rearrange the density equation shown in Equation 2 to solve for mass, as shown in Equation 3.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad \textit{Equation 2}$$

$$\text{Mass} = \text{Volume} \times \text{Density} \qquad \textit{Equation 3}$$

Success of this laboratory activity depends on the ability to take accurate measurements to make valid estimations and to apply the rules for significant figures in mass and volume (and density) calculations.

Safety Precautions

All activities in this lab are considered nonhazardous. Please follow all laboratory safety guidelines.

Pre-Lab Activity — *Length and Area*

Materials (for each lab group)

Calculator

Metric ruler, 0.1 cm markings

Procedure

Reading the Metric Ruler

1. Obtain a metric ruler. Take a close look at the markings on the ruler. What is the distance between the smallest markings on the ruler?

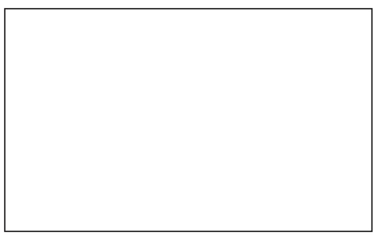
2. It is generally accepted that scientific measurements can be estimated to one-tenth of the smallest mark on the instrument. Therefore, if a ruler has a marking every 1 cm, a person can reliably estimate to the nearest 0.1 cm. Likewise, if a ruler has a marking every 0.1 cm, a person can reliably estimate to the nearest 0.01 cm. With the metric ruler provided by your instructor, what is the most reliable estimation that can possibly be made?

3 Use the metric ruler to measure the length of the following line segments. Be sure to estimate to the hundredths place for each measurement. Be sure to include the appropriate units for length. Underline the digit that you estimated while measuring.

Measure These Line Segments	***Measurement***
a.	__________
b.	__________
c.	__________

Applying Significant Figures in Calculations

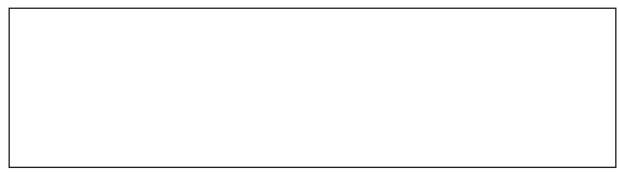
4. Use the metric ruler to measure the length and width of each of the rectangles below. Be sure to estimate to the proper decimal place for each measurement and to include units with each measurement. Underline the digit that you estimated while measuring.



Rectangle #1

Length: __________

Width: __________



Rectangle #2

Length: __________

Width: __________

5. To calculate the area of the rectangles, multiply the length by the width. Round the area values to the proper number of significant figures. Be sure to include the appropriate units for area.

Area of Rectangle #1:__________

Area of Rectangle #2:__________

Experiment #1 — *Density Calculation*

Materials (for each lab group)

Balance

Calculator

Metric ruler, 0.1 cm markings

Plastic blocks, 3

Procedure

1. Obtain a plastic block from your teacher. Record the block number and color of the block in the table below.
2. Use the laboratory balance to measure the mass of the block. Record the mass in the data table.
3. Use the metric ruler to measure the dimensions of the block. Record these values in the data table.
4. Calculate the volume of the block using Equation 1 from the background information. Round the answer to the proper number of significant figures. Record the volume in the data table. Be sure to include the appropriate units.
5. Calculate the density of the plastic block using Equation 2 from the background information. Record the density in the data table. Be sure to include the appropriate units.
6. Repeat steps 1–5 for two additional blocks, being sure to obtain blocks of different colors. Record all data in the table below.
7. Check with your instructor to determine the accuracy of your measurements and calculations.

Data Table

Block Number			
Color of Block			
Mass (g)			
Length (cm)			
Width (cm)			
Height (cm)			
Volume (cm^3)			
Density (g/cm^3)			

Experiment #2 — *The Measurement Challenge*

Materials (for each lab group)

Balance

Calculator

Metric ruler, 0.1 cm markings

Plastic block

Procedure

1. Obtain a plastic block from your teacher. Record the block number and color of the sample. The block number must be different from any of the block numbers used in Experiment #1.

   Block Number: ______________ ***Color of Block:*** ______________

2. Measure the dimensions (length, width, and height) of the block. Be sure to estimate all measurements to the correct decimal place and to include units with each measurement.

   Length: __________ ***Width:*** __________ ***Height:*** __________

3. Calculate the volume of the block using Equation 1. Round the answer to the proper number of significant figures. Record the volume in the data table. Be sure to include the appropriate units.

   Volume: __________

4. Use the known density value and the volume calculated in question 3 to predict the mass of the plastic sample. The known density values for each different type of colored plastic are shown in the table below. The density equation can be rearranged to solve for mass as shown in Equation 3.

Color of Block	Density (g/cm^3)
Paper-white	0.51
Black	0.96
Milky-white	0.91
Clear	1.17
Gray	1.41

   Predicted Mass of Block: ______________

5. When the mass of the plastic block has been calculated and a prediction made, bring the block to the teacher. The teacher will measure the actual mass of the block using a laboratory balance.

   Actual Mass Measurement: ____________ ***Teacher Initials:*** _________
   (To be filled in by the teacher)

6. Determine the accuracy of the mass calculation by comparing the predicted (calculated) mass with the actual (measured) mass. Calculate the percent error (or difference) in the mass calculation using the equation below. (Or the teacher will perform the error calculation at the balance right in front of the student. Instant feedback!)

$$\text{Percent Error} = \frac{|\text{Calculated Mass} - \text{Actual Mass}|}{\text{Actual Mass}} \times 100$$

Experiment #3 — *The Measurement Challenge (A More Open-Ended Version)*

Materials (for each lab group)

Balance

Calculator

Metric ruler, 0.1 cm markings

Plastic block

Procedure

1. Obtain a plastic block from your teacher. Record the block number and color of the sample. The block number must be different from any of the block numbers used in Experiment #1.

   Block Number: ______________ ***Color of Block:*** ______________

2. Use the known density value to predict the mass of the plastic sample. The known density values for each different type of colored plastic are shown in the table below.

Color of Block	Density (g/cm^3)
Paper-white	0.51
Black	0.96
Milky-white	0.91
Clear	1.17
Gray	1.41

   Necessary Calculations: (Show all work)

   Predicted Mass of Block: ______________

3. When the mass of the plastic block has been calculated and a prediction made, bring the block to the teacher. The teacher will measure the actual mass of the block using a laboratory balance.

   Actual Mass Measurement: ____________ ***Teacher Initials:*** _________
   (To be filled in by the teacher)

4. Determine the accuracy of the mass calculation by comparing the predicted (calculated) mass with the actual (measured) mass. Calculate the percent error (or difference) in the mass calculation using the equation below. (Or the teacher will perform the error calculation at the balance right in front of the student. Instant feedback!)

$$\text{Percent Error} = \frac{|\text{Calculated Mass} - \text{Actual Mass}|}{\text{Actual Mass}} \times 100$$

Teacher's Notes

Measurement Challenge

Materials Included in Kit

Plastic blocks, different densities and colors, 30

Additional Materials Needed (for each lab group)

Balance

Calculator

Metric ruler, 0.1 cm markings

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter

Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter

Tips

- This laboratory kit contains enough materials for unlimited use by a class of 30 students. The activities can be performed in a standard 50-minute lab period.
- Experiment #1 may be used as a traditional classroom density experiment. All students can start with Experiment #1 and then go on to do either Experiment #2 or #3.
- Experiments #2 and #3 serve as higher-level authentic assessment labs for the determination of density. Each student should receive his or her *own* plastic density block so that each student is held accountable. Be sure the block number is different than the one used in Experiment #1.
- Measurement errors include limitations of the ruler (thickness of the ruler, line width, systematic error, etc.) and the human eye (students with sight problems, parallax, random error, etc.).
- There is a large normal variation in the density of each plastic. In contrast to the density of a pure substance, such as copper, which can be known with a high degree of accuracy, the density of a plastic material depends on the molecular weight of the polymer, the degree of branching in the polymer chain, the presence of fillers, etc.
- The identity and density range for each plastic are shown below.

Color	Identity	Density Range (g/cm^3)	Percent Uncertainty
White	Sintra	0.48–0.54	5.8%
Black	High-density Polyethylene	0.94–0.98	2.1%
Milky white	Polypropylene	0.89–0.93	2.2%
Clear	Acrylic	1.13–1.21	3.4%
Gray	Polyvinyl Chloride	1.36–1.46	3.5%

- The expected percent error in the mass calculations for Experiments #2 and 3 depends on the material. The largest percent error will probably be found for the paper-white Sintra blocks because the relative uncertainty in the density is (0.03/0.51) × 100 or 6%. The percent uncertainty in the density for each plastic is shown above.
- Sintra is an "expanded" polyvinyl chloride (PVC). The density of the Sintra blocks may change over time due to outgassing or compacting.

Teacher's Notes *continued*

- Block dimensions vary slightly from kit to kit. Therefore, exact dimensions for each block are not provided for the teacher. It is suggested that an independent "master measurement sheet" be made for each block provided in the kit prior to class. Teachers may wish to number the blocks from 1 to 30 when creating a key. It will take about an hour to measure the dimensions, weigh the blocks, and calculate the volumes and densities for all 30 blocks. After students have completed their measurements and calculations, collect and enter the student data into a spreadsheet. Standard deviations and the effects of measurement error can then be revealed. The large pool of data may make it helpful to determine the "acceptable" error for each of the five types of blocks.

Introducing Experiment #1 — Density Calculations

- Give each student only pages 1–3 of the handout—Experiment #1. Do not hand out Experiment #2 or #3 yet since the purpose of Experiment #1 is to determine density, and Experiments #2 and #3 supply the known densities.
- Students will determine the density of three plastic blocks. Give each student one block to start. When done with the first block, have the student return the block to you in exchange for a second block and then a third block, each should be a different color. Do not allow students to simply trade blocks on their own since the goal is to learn to measure and calculate, and students may be tempted to share measurement data.
- Students should be comfortable with reading a ruler to the proper number of digits. Remind students that they should be able to estimate their measurements to the hundredths place with rulers that have markings every 0.1 cm.
- The pre-laboratory activity will help to reinforce the proper use of rulers and estimating to the appropriate number of significant digits. The recommended sequence is such that students progress from measuring the lengths of line segments to determining the area for rectangles and finally to determining the volume of the blocks. This sequence allows the students to advance from simple one-dimensional measurements to two- and three-dimensional calculations.
- In grading the accuracy of the predicted mass of different block, please keep in mind the percent uncertainty in the average density of each plastic.
- Teachers may wish to use Experiment #1 as a traditional density experiment where students become proficient in the proper use of laboratory balances, rulers, and density calculations. Students often experience difficulty initially with distinguishing between the related terms of *mass, volume,* and *density*. Teachers should emphasize these definitions so that students use these scientific terms properly.

Introducing Experiment #2 or #3 — The Measurement Challenge

- Each student should be given a copy of either Experiment #2 or Experiment #3. While both experiments are high level, teachers who prefer a more open-ended approach may wish to use Experiment #3, which forces students to plan their own mathematical strategy. Tell students that the overall goal in either experiment is to use a ruler and the known density values to predict the mass of their plastic block. This should be clearly stated to clarify the students' task.
- Each student should be given a ruler and one plastic block sample with a different block number from that used in Experiment #1. The blocks should be distributed so that students receive alternating colors. By varying the colors of the samples, the students are less likely to compare answers with the other students sitting near them. Remind students that each color of plastic has a different density value, which will impact their eventual mass calculations.
- Remind students that they will be assessed on the accuracy of their predicted mass to the actual mass. Students frequently incorrectly label their calculated volume as being their block's mass. Caution them about this error.
- Teachers are encouraged to stand at the laboratory balance while students are measuring the dimensions of the plastic blocks. Students may be tempted to gain an advantage (i.e., cheat) by measuring the actual mass of their plastic sample if they have easy access to any laboratory balances!

Sample Answers to Pre-Lab Activity

Reading the Metric Ruler

1. Obtain a metric ruler. Take a close look at the markings on the ruler. What is distance between the smallest markings on the ruler?

   The smallest markings on the ruler are 0.1 cm.

2. It is generally accepted that scientific measurements can be estimated to one-tenth of the smallest mark on the instrument. Therefore, if a ruler has a marking every 1 cm, a person can reliably estimate to the nearest 0.1 cm. Likewise, if a ruler has a marking every 0.1 cm, a person can reliably estimate to the nearest 0.01 cm. With the metric ruler provided by your instructor, what is the most reliable estimation that can possibly be made?

   A ruler with markings every 0.1 cm provides measurements to the nearest 0.01 cm.

3. Use the metric ruler to measure the length of the following line segments. Be sure to estimate to the hundredths place for each measurement. Underline the digit that you estimated.

   Measurement ranges are given below. Answers may vary because of the limitiations of the ruler and of the human eye. The last digit is underlined because this the the estimated digit and may vary.

   Line a = 2.80–2.90 cm

   Line b = 1.35–1.45 cm

   Line c = 3.65–3.75 cm

Applying Significant Figures in Calculations

4. Use the metric ruler to measure the length and width of each of the rectangles below. Be sure to estimate to the proper decimal place for each measurement and to include units with each measurement.

   Measurement ranges are given below. Answers may vary because of the limitiations of the ruler and of the human eye. The last digit is underlined because this the the estimated digit and may vary.

   Rectangle #1: Length = 4.85–4.95 cm; Width = 2.90–3.00 cm

   Rectangle #2: Length = 8.00–8.10 cm; Width = 2.05–2.15 cm

5. To calculate the area of the rectangles, multiply the length by the width. Round the area values to the proper number of significant figures. Be sure to include the appropriate units for area.

   Measurement ranges are given below. Answers may vary because of the limitiations of the ruler and of the human eye. The last digit is underlined because this the the estimated digit and may vary.

   Rectangle #1: Area = 14.1–14.9

   Rectangle #2: Area = 16.4–17.4

Acknowledgment

Special thanks to Jeff Bracken, chemistry teacher at Westerville North High School, Westerville, OH for developing this unique and ingenious laboratory activity.

Reference

Plumsky, R. *J. Chem. Educ.* **1996,** *73,* 451–454.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Measurement Challenge* activity, presented by Jeff Bracken, is available in *Measurement Lab Activities* and in *Jeff Bracken Challenge Labs,* part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for the *Measurement Challenge* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Measurement Challenge—A Density Laboratory Kit* available from Flinn Scientifc. Materials may also be purchased separately.

Catalog No.	Description
AP5939	Measurement Challenge—A Density Laboratory Kit
AP5387	Rulers, Metric/English, Clear

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.