Lab 1: Measurement of Density and Temperature Study

Objectives: To investigate the concepts of accuracy and precision and to review the use of significant figures in measurements and calculations. Students will learn how to work with laboratory measuring equipment and properly report mass, length, volume, and temperature. These concepts will be applied in the determination of the density and temperature of substances.

Materials: Solid metallic objects (aluminum, zinc, iron, and copper pieces); ice, corn syrup, glycerin, rubbing alcohol, salt water.

Equipment: density cube set; 10 mL and 50 mL graduated cylinder; 150 mL beaker; 50 mL volumetric flask; 50 mL Erlenmeyer flask, top-loading balance; deionized water for density measurement; glass thermometer; Vernier temperature probe; ruler.

Safety: Gloves and safety goggles should be worn at all times while in the lab.

Waste disposal: All solutions may be flushed down the drain with plenty of tap water; solid metal shot/beads can be dried and placed in a collecting container as directed by your instructor.

Review: Rules for significant figures

INTRODUCTION

All scientific investigations involve making measurements. A measured value, however, is only as good as the equipment or tools used to obtain and make the measurement. It is important, therefore, to follow certain guidelines when making measurements or using measured values in calculations.

Consider measuring the mass of an object using a top-loading balance that can be read to the nearest 0.1 grams. The display on the balance indicates that the mass of the object is 42.5 grams. We would record the mass as 42.5 ± *0.1* g, which means we are fairly confident that the actual mass is between 42.*4* g and 42.*6* g. The uncertainty in our recorded mass would be ± 0.1 g. If we measured the mass of the same object with an analytical balance, we might obtain a value of 42.467 g ± 0.*001*, which implies a mass between 42.46*6* g and 42.46*8* g. The uncertainty in any measurement is usually implied as plus or minus 1 in the last recorded unit. Clearly, the uncertainty in the mass obtained using the analytical balance is much less than the uncertainty in the top-

loading balance. The uncertainty of a measurement depends on the sensitivity of the instrument and determines the number of significant figures used when recording the measured value.
Ideally, the measured values obtained in the laboratory reflect the true value we are trying to measure. The accuracy of our measurements is reflected in how close they are to the correct value. To ensure accurate results, scientists often make several measurements and then average them so that the error in any given measurement will be minimized. Agreement between multiple measurements is known as precision. Good precision does not necessarily ensure accuracy, however. Consider the following data obtained for the mass of an object on two different balances.

	Balance #1	**Balance #2**
Measurement #1	27.4 g	27.8 g
Measurement #2	26.9 g	26.1 g
Measurement #3	27.1 g	26.7 g
Average	27.1 g	26.9 g

The range of measurements for balance #1 is from 26.9 to 27.4, or only 0.5 g, while the range for balance #2 is from 26.1 to 27.8, or 1.7 g. The precision of measurements for balance #1 is better (i.e., better agreement between measurements), but is it more accurate? If the true mass of the object was 26.9 g, then the value obtained using balance #2 would be more accurate, although less precise.

We indicate the precision of a measured value by the number of significant figures we use to record it. Typically, the appropriate number of significant figures will depend on the sensitivity of the instruments we used to obtain the value. If these measured values are then used in a calculation, the precision of the final calculated answer will depend on the precision of the measured values used in the calculation. The calculated answer CANNOT be more precise than the values used in the calculation. It may be worthwhile to review the section in your textbook that discusses the rules for significant figures in calculations before beginning this lab exercise.

In this exercise we will use various approaches to determine the mass and volume of both solid objects and solutions and use these measured values to calculate *density*. Density, defined as the mass per unit volume, is an intrinsic property of matter that is often used to identify unknown substances. It is important to record measured results to the appropriate number of significant figures, based on the precision of the equipment or instrument used. Mass is measured using an **analytical balance**, such as that illustrated in Figure 1.1.

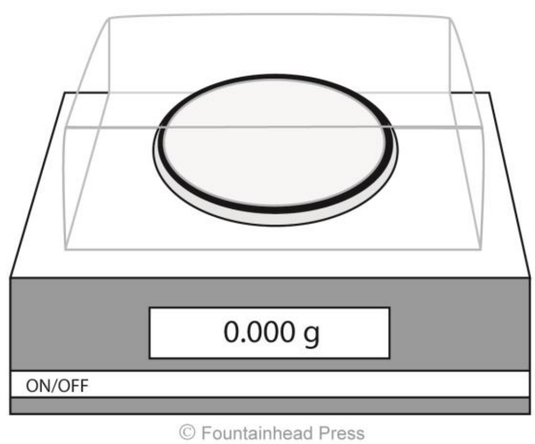
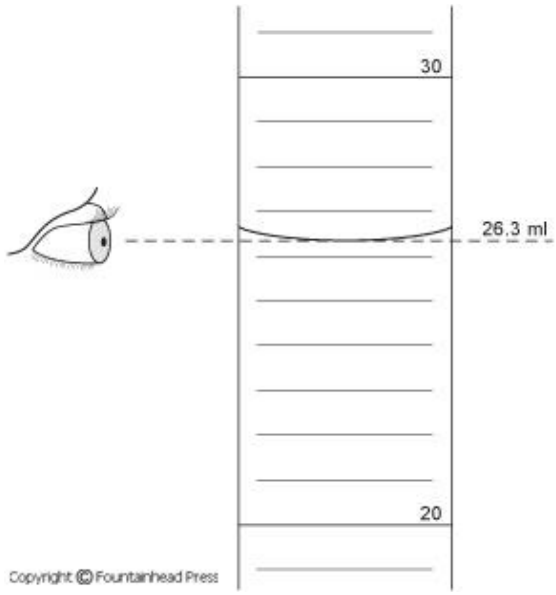


Figure 1.1. Analytical balance with precision of ± 0.001 g (1 mg).



Volumes of liquids are typically measured using **graduated** glassware, or equipment that is marked with lines to indicate the volume of the liquid. When reading volumes from graduated glassware it is important to read the liquid level at the bottom of the meniscus, or curved surface, while viewing the meniscus at eye level, as illustrated in Figure 1.2. In this case, the first two significant figures are easily determined, but the last significant figure is estimated.

Figure 1.2. Reading volumes in graduated glassware.

Volumes of liquids can be measured directly using appropriate glassware, but the volumes of irregularly shaped solids must be determined by the volume of liquid displaced by that solid. For example, suppose you wanted to measure the volume of a spherical object. One way to do this would be to partially fill a graduated cylinder with water. Then, place the spherical object in the graduated cylinder. The water level will rise due to the added object. The volume of the solid can be calculated as the difference between the initial and final liquid levels in the graduated cylinder.

In this lab you will determine the density of both liquids and solids. The density of solid substances is typically reported in units of g/cm^3, while the density of liquids is typically reported in units of g/mL. Since 1 cm^3 = 1 mL, these units are often used interchangeably.

$$Density\ \left(\frac{g}{mL}\right) = \frac{mass\ (g)}{volume\ (mL)}$$ **Equation 1.1**

$$volume\ (mL) = \frac{mass\ (g)}{Density\ \left(\frac{g}{mL}\right)}$$ **Equation 1.2**

Another important measurement in scientific studies is temperature, the measure of hot or cold a substance is. Like density, temperature can be measured in Fahrenheit (˚F), Celsius (˚C), or Kelvin (K) unit. The units of temperature can be converted using the following equations:

$T_F = 1.8\ T_C + 32$ **Equation 1.3**

$T_C = \frac{T_F - 32}{1.8}$ **Equation 1.4**

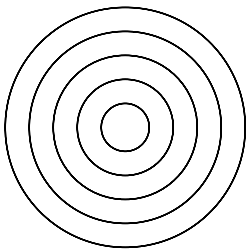
$K = T_C + 273.15$ **Equation 1.5**

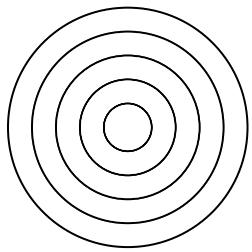
In the first part of this experiment, you will learn to how determine the density of liquids, regular shaped solids. In the second part, you will investigate the precision of common laboratory measuring tools.

*Name:*___________________________________
Section: ___________________ *Date:*___________________

Pre-Lab Questions

1. Use the three targets below to indicate the accuracy and precision of the following sets of measurements:
   (a) Place four Xs to represent data points with good accuracy but poor precision.
   (b) Place four Xs to represent data points with good precision but poor accuracy.
   (c) Place four Xs to represent data points with good accuracy and good precision.


(a)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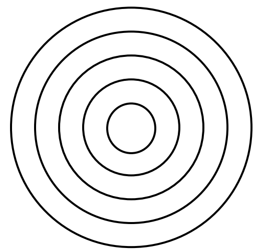
(c)

2. Write the implied range for a temperature recorded as 38.9 ºC.

3. Define each of the following terms with regard to scientific measurements.

   i. accuracy –

   ii. precision –

   iii. sensitivity –

   iv. uncertainty –

4. Indicate the number of significant figures in each of the following:

   (a) 20.05 _________________ (b) 2.37×10^{-2} _________________
   (c) 1.460 _________________ (d) 0.0462 _________________
   (e) 3040 _________________ (f) 3.040×10^{3} _________________

5. Perform the following calculations and report the answer to the appropriate number of significant figures:

   (a) 48.3 mL – 9.27 mL = ___________ (b) (17.36 g) / (22.0 mL) = ___________

6. A student determines the density of a solid object using the procedures described in Part IB of this exercise. The following data is obtained:

Mass of object(s):	51.16 grams
Volume of water:	48.9 mL
Volume of water + objects(s):	54.7 mL
Volume of object(s):	_____ mL
Density of unknown solid:	_____ g/mL

Complete the calculations to find the density of the unknown solid object. Show your calculations below.

PROCEDURE

I. Density of substances

Part IA – Density of a Liquid

Determine the density of an unknown liquid by measuring its mass and volume, identify the liquid using its calculated density.

1. Obtain a sample of unknown liquid and record its ID on the data sheet.

2. Weigh a clean and dry 10 mL graduated cylinder and record the mass on the data sheet.

3. Add the unknown liquid sample to the graduate cylinder until the meniscus sits on to the 10 mL mark. Record the volume of liquid to the nearest 0.01 mL. Be sure to read the volume at the bottom of the meniscus and at eye level. (Note: You need to estimate the last digit.)

4. Place the graduated cylinder + liquid on the balance and record the mass.

5. Empty graduated cylinder in the sink, rinse three times with tab water and two times with deionized water.

Part IB – Density of an Irregularly Shaped Solid by Displaced Volume of Water

The volume of an irregularly shaped solid can be determined by measuring the volume of water it displaces. In this part, you will determine the volume of an unknown irregularly shaped solid, calculate its density and identify the unknown sample.

6. Obtain a sample of an unknown solid sample and record its ID on the data sheet.

7. Weight out approximately 20 grams of the unknown solid and record the mass as it displays on the balance on the data sheet.

8. Fill a 50 mL graduated cylinder about halfway with water and record the volume to the nearest 0.01 mL. (Note: You need to estimate the last digit.)

9. Carefully add all the unknown solid to the graduated cylinder. Shake gently to release any air bubbles. Record the volume of water + solid in the graduated cylinder. The difference between this new volume and the volume recorded in previous step is the volume displaced by the unknown solid.

10. Carefully discard water in the sink and collect the solid in designated containers in the fume hood.

Investigating Accuracy of Measuring Tools

Part IIA – Measuring Length

Investigate the accuracy of two measuring tools: a ruler and a digital caliper, by using the density data. Density is a measure of mass over volume, so the accuracy of the calculated density depends on the accuracy of the tools used to measure mass and length of an object.

11. Take a solid block from “Density Block” box. Record the type of the block and its actual density on the data sheet.

12. Weigh the block and record its mass on the data sheet.

13. Measuring the length using a ruler:
    a. Obtain a ruler, use the centimeters side to measure the length of one side of the cube to the nearest 0.01 cm, you need to estimate the last digit. Keep a note of the measurement.
    b. Measure two more sides and record the average of three measurements.

14. Measuring the length using a digital caliper.
    a. The reading on digital display must be 0.00 when the caliper jaws are closed. You may need to press ZERO to calibrate the caliper.
    b. The measurements must be taken in units of millimeter.
    c. Measure the length of three sides of the cube and average. Make sure that the jaws are tight against the sides of the cube.
    d. Turn off the caliper and return to the storage box.
    e. Convert the average to units of centimeters and record on datasheet.

15. Return the solid block to the box.

PART IIB – Measuring Volume

Determine which piece of glassware is the most accurate for measuring 50 mL of a liquid: a 50 mL graduated cylinder, a 50 mL Erlenmeyer flask, and a 50 mL volumetric flask.

Add 50 mL water to each glassware, use mass and density data to calculate the actual volume of water that each container holds.

16. Weigh a clean and dry 50 mL graduated cylinder and record on the data sheet.

17. Add **deionized** water until the meniscus sits on to the 50 mL line.

18. Place the graduated cylinder + water on balance and record the mass on the data sheet.

19. Repeat steps in PART IIB with a 50 mL clean and dry Erlenmeyer flask and a 50 mL volumetric flask.

Once you have completed this part, empty the Erlenmeyer flask and volumetric flask, use a paper towel to dry the outside of the flasks and place them in the oven to dry for the next class.

PART IIC – Measuring Temperature

You will measure the temperature of three samples of water using two thermometers, a glass thermometer, and a digital temperature probe to determine which tool provides a more accurate measurement of the temperature.

20. Obtain a glass thermometer and a digital Vernier temperature probe, a hot plate, and a magnetic stir bar.

Figure 1.3. LabQuest Mini interface and temperature probe

21. Obtain three clean 150 mL beakers. Add about 50 mL tap water to one beaker, 100 mL ice to the second beaker, and 50 mL deionized water to the third beaker.

22. Carefully add the stir bar to the beaker filled with deionized water and place it on the hot plate. Start stirring on medium. You may need to move the beaker to center on the hot plate. Once the stirrer position and speed are adjusted, start heating the beaker on medium (set the dial on 5-6).

23. While waiting for deionized water to boil, log into the computer in your station using your NIU credentials and open Logger Pro software on desktop. Plug in the temperature probe into CH1 of LabQuest Mini interface. See Figure 1.4 for Logger Pro display.

24. Measure the temperature of ice and tap water with temperature probe. You do not need to press the Collect button, just record the “live” temperature readouts on data sheet.

25. Next, measure and record the temperature of ice and tap water with glass thermometer.

26. When water comes to boil in deionized water beaker measure and record the temperature using temperature probe and glass thermometer. You must keep the temperature probe’s cable away from the hot plate. Be careful as vapor is very hot and can cause sever burn.

27. Turn off the hot plate and stirrer.

28. Use a beaker tong or hot gloves to remove the beaker from hot plate and let cool down.

29. Once you have recorded the temperatures, pour the contents of the beakers in the drain.

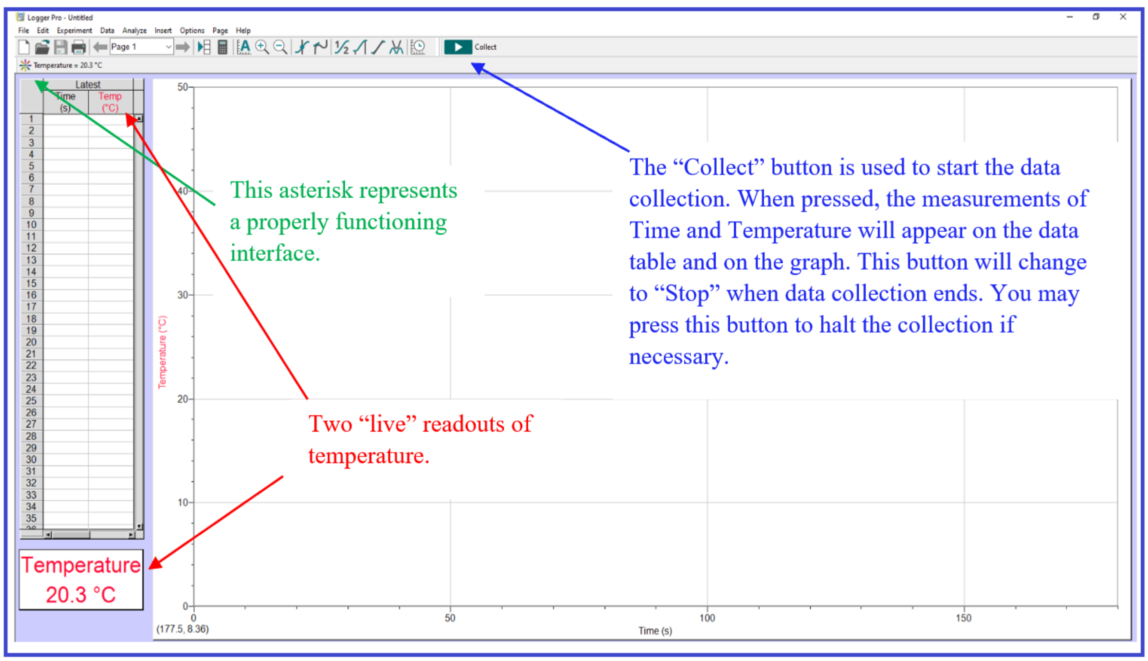

Figure1.4. Logger Pro display

CALCULATIONS

Part IA– Density of a Liquid

1. Subtract the mass of the empty graduated cylinder from the mass of the cylinder + solution. This difference is equal to the mass of the unknown solution.
2. Density is defined as: d = mass / volume. Calculate the density of unknown solution and record it on your data sheet to the appropriate number of significant figures.
3. Use the density of liquids in Table 1.1 to identify the unknown liquid.

Table 1.1. Density of some liquids

Liquids	Density (g/mL)
Corn syrup	1.40
Glycerin	1.26
Salt water	1.15
Water	1.00
Rubbing alcohol	0.79

Part IB– Density of a Solid by Displaced Volume of Water

1. Subtract the initial volume of water from the volume of water + solid to obtain the volume of the unknown solid by difference.
2. Calculate the density of the solid and record it on your data sheet to the appropriate number of significant figures.
3. Use the density of solids in Table 1.2 to identify the unknown solid.

Table 1.2. Density of some solids

Solids	Density (g/mL)
Aluminum	2.70
Copper	8.96
Steel	7.85
Lead	11.35
Zinc	7.13
Brass	8.47
Acrylic	1.18
Polyethylene	0.94
Nylon	1.15
Poplar	0.52*
Red Oak	0.74*
Willow	0.61*

* Density of wood varies based on the region and humidity.

Part IIA – Measuring Length

1. Volume of a cube is calculated as:

$$\text{Volume (cm}^3) = a \times a \times a \qquad \textbf{Equation 1.6}$$

Where “a” is the edge of cube in **cm**.

2. Divide mass of cube by its volume to calculate its density in units of g/cm^3.

3. Calculate %error for your result.

$$\%\text{error} = \frac{|\text{actual value} - \text{experimental value}|}{\text{actual value}} \times 100 \qquad \textbf{Equation 1.7}$$

See Table 1.2 for actual density values.

Part IIB – Measuring Volume

1. Plug density of water at room temperature into Equation 1.2 to calculate volume of water (mL) in each piece of glassware.

2. Calculate %error between experimental (calculated) volume of water and the actual value (volume mark on the glassware).

Table 1.3. Density of Water at various Temperatures

Temp. (ºC)	Density(g/mL)	**Temp. (ºC)**	Density (g/mL)
14.0	0.99999	**20.0**	0.99823
15.0	0.99913	**21.0**	0.99800
16.0	0.99896	**22.0**	0.99777
17.0	0.99879	**23.0**	0.99754
18.0	0.99862	**24.0**	0.99732
19.0	0.99845	**25.0**	0.99707

Part IIC – Measuring Temperature

Calculate %error for measured temperature of ice (frozen water) and boiling water. The actual freezing point and boiling point of water are:

Freezing point of water = 0.00°C
Boiling point of water = 100.00 °C

Data Sheet

PART IA – Density of a Liquid

Unknown ID: ____________________

Mass of empty graduated cylinder (g)	
Mass of graduated cylinder + liquid (g)	
Mass of liquid (g)	
Volume of liquid (mL)	
Density of liquid (g/mL)	

Identification of unknown liquid sample: ________________________

Show calculations:

PART IB – Density of a Solid by Displaced Volume of Water

Unknown: _______________________

Mass solid (g)	
Volume of water in graduated cylinder (mL)	
Volume of water in graduated cylinder + solid (mL)	
Volume of solid (mL)	
Density of solid (g/mL)	

Identification of unknown solid sample: ________________________

Show calculations:

Data Sheet

PART IIA – Measuring Length

Solid cube:_________________________

Actual density of cube: ______________

	Ruler	**Digital caliper**
Mass of cube (g)		
Average Edge of solid cube (cm)		
Volume of solid (cm^3)		
Density of solid (g/ cm^3)		
% Error in calculated density		

Show sample calculations.

PART IIB– Measuring Volume

Room Temperature: ___________

Density of water at room temperature: ___________

	50.0 mL **Graduated Cylinder**	**50. 0 mL** **Erlenmeyer Flask**	**50.0 mL** **Volumetric Flask**
Mass of empty dry glassware (g)			
Mass of glassware + water (g)			
Mass of water (g)			
Calculated volume of water (mL)			
% Error in calculated volume			

Show sample calculations.

PART IIC– Measuring Temperature

	Temperature of Tap water	**Temperature of Boiling water**	**Temperature of Ice water**
Glass Thermometer			
Temperature in °C			
Temperature in K			
% Error in measured temperature			
Digital Temperature Probe			
Temperature in °C			
Temperature in K			
% Error in measured temperature			

Post-Lab Questions

1. How many significant figures did you report for density in Part IA? Which measured value was the determining factor? Explain.

2. In part IIA, you calculate the density of a cube using a ruler and a digital caliper to measure its sides.

a) Which measuring tool has a higher precision? Why?

b) Which calculated density has less uncertainty? Explain.

3. In part IIB, you measured 50 mL of water using a graduated cylinder, an Erlenmeyer flask, and a volumetric flask. Based on your results, which piece of glassware most accurately measures 50 mL of water? Explain.

4. If you repeated the measurements in part IIC several times, which measurement do you think would give greater precision: glass thermometer or digital temperature probe? Why?

5. There is a very old riddle which asks, "Which weighs more—a pound of gold or a pound of feathers?" The most common answer (gold) is not correct. Explain the problem in reasoning that might cause someone to give a wrong answer.