3.4 Density

Connecting to Your World Have you ever wondered why some objects float in water, while others sink? If you think that these lily pads float because they are lightweight, you are only partially correct. The ratio of the mass of an object to its volume can be used to determine whether an object floats or sinks in water. For pure water at 4°C, this ratio is 1.000 g/cm^3. If an object has a mass-to-volume ratio less than 1.000 g/cm^3, it will float in water. If an object has a mass-to-volume ratio greater than this value, it will sink in water.

Guide for Reading

Key Concepts

- What determines the density of a substance?
- How does a change in temperature affect density?

Vocabulary

density

Reading Strategy

Identifying Main Ideas As you read, write the main idea of the text that follows each heading.

Determining Density

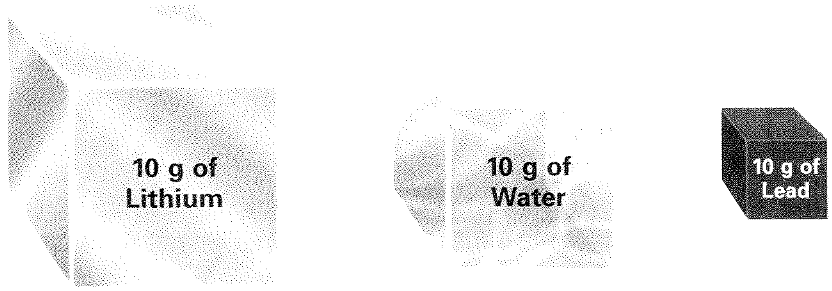
Perhaps someone has tricked you with this question: "Which is heavier, a pound of lead or a pound of feathers?" Most people would not give the question much thought and would incorrectly answer "lead." Of course, a pound of lead has the same mass as a pound of feathers. What concept, instead of mass, are people really thinking of when they answer this question?

Most people are incorrectly applying a perfectly correct idea: namely, that if a piece of lead and a feather of the same volume are weighed, the lead would have a greater mass than the feather. It would take a much larger volume of feathers to equal the mass of a given volume of lead.

Interactive Textbook

Simulation 1 Rank materials according to their densities.

with ChemASAP



Volume	19 cm^3	10 cm^3	0.88 cm^3
Density	0.53 g/cm^3	1.0 g/cm^3	11.4 g/cm^3

Figure 3.13 A 10-g sample of pure water has less volume than 10 g of lithium, but more volume than 10 g of lead. The faces of the cubes are shown actual size. **Inferring** ***Which substance has the highest ratio of mass to volume?***

Table 3.6

Densities of Some Common Materials

Solids and Liquids		Gases	
Material	**Density at 20°C (g/cm³)**	**Material**	**Density at 20°C (g/L)**
Gold	19.3	Chlorine	2.95
Mercury	13.6	Carbon dioxide	1.83
Lead	11.4	Argon	1.66
Aluminum	2.70	Oxygen	1.33
Table sugar	1.59	Air	1.20
Corn syrup	1.35–1.38	Nitrogen	1.17
Water (4°C)	1.000	Neon	0.84
Corn oil	0.922	Ammonia	0.718
Ice (0°C)	0.917	Methane	0.665
Ethanol	0.789	Helium	0.166
Gasoline	0.66–0.69	Hydrogen	0.084

The important relationship in this case is between the object's mass and its volume. This relationship is called density. **Density** is the ratio of the mass of an object to its volume.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

A 10.0-cm^3 piece of lead, for example, has a mass of 114 g. What, then, is the density of lead? You can calculate it by substituting the mass and volume into the equation above.

$$\frac{114\ \text{g}}{10.0\ \text{cm}^3} = 11.4\ \text{g/cm}^3$$

Note that when mass is measured in grams, and volume in cubic centimeters, density has units of grams per cubic centimeter (g/cm^3).

Figure 3.13 on page 89 compares the density of three substances. Why does each 10-g sample have a different volume? The volumes vary because the substances have different densities. **Density is an intensive property that depends only on the composition of a substance, not on the size of the sample.** With a mixture, density can vary because the composition of a mixture can vary.

What do you think will happen if corn oil is poured into a glass containing corn syrup? Using Table 3.6, you can see that the density of corn oil is less than the density of corn syrup. For that reason, the oil floats on top of the syrup, as shown in Figure 3.14.

You have probably seen a helium-filled balloon rapidly rise to the ceiling when it is released. Whether a gas-filled balloon will sink or rise when released depends on how the density of the gas compares with the density of air. Helium is less dense than air, so a helium-filled balloon rises. The densities of various gases are listed in Table 3.6.

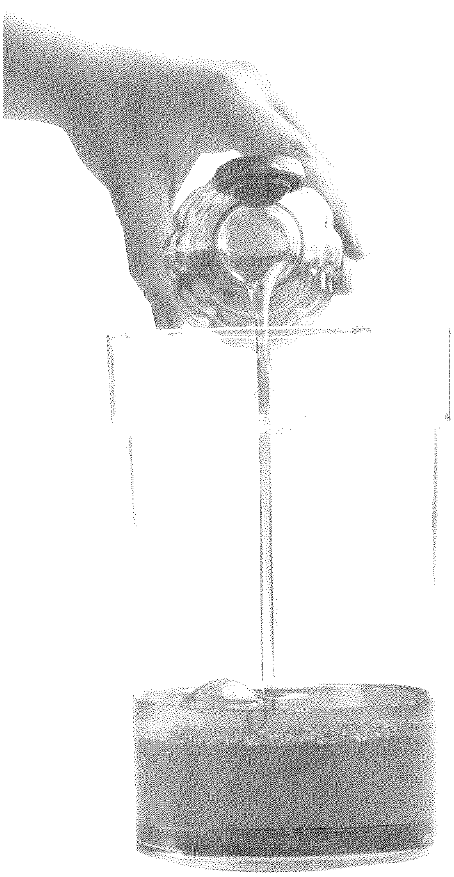


Figure 3.14 Because of differences in density, corn oil floats on top of corn syrup.

Checkpoint ***What quantities do you need to measure in order to calculate the density of an object?***

Density and Temperature

Experiments show that the volume of most substances increases as the temperature increases. Meanwhile, the mass remains the same despite the temperature and volume changes. Remember that density is the ratio of an object's mass to its volume. So if the volume changes with temperature (while the mass remains constant), then the density must also change with temperature. **The density of a substance generally decreases as its temperature increases.** As you will learn in Chapter 15, water is an important exception. Over a certain range of temperatures, the volume of water increases as its temperature decreases. Ice, or solid water, floats because it is less dense than liquid water.

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For: Links on Density
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SAMPLE PROBLEM 3.10

Calculating Density

A copper penny has a mass of 3.1 g and a volume of $0.35\ cm^3$. What is the density of copper?

1 Analyze ***List the knowns and the unknown.***

Knowns
- mass = 3.1 g
- volume = $0.35\ cm^3$

Unknown
- density = ? g/cm^3

Use the known values and the following definition of density.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

2 Calculate ***Solve for the unknown.***

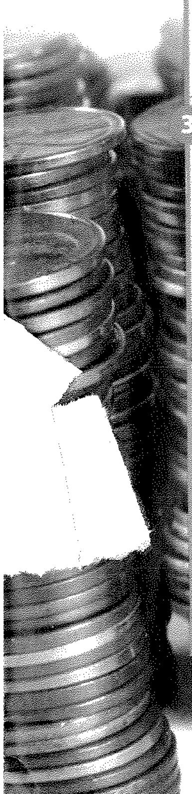
The equation is already set up to solve for the unknown. Substitute the known values for mass and volume, and calculate the density.

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{3.1\ \text{g}}{0.35\ \text{cm}^3} = 8.8571\ \text{g/cm}^3$$

$$= 8.9\ \text{g/cm}^3 \text{ (rounded to two significant figures)}$$

3 Evaluate ***Does the result make sense?***

A piece of copper with a volume of about $0.3\ cm^3$ of copper has a mass of about 3 grams. Thus, about three times that volume of copper, $1\ cm^3$, should have a mass three times larger, about 9 grams. This estimate agrees with the calculated result.



Math Handbook

For help with algebraic equations, go to page R69.

Practice Problems

46. A student finds a shiny piece of metal that she thinks is aluminum. In the lab, she determines that the metal has a volume of $245\ cm^3$ and a mass of 612 g. Calculate the density. Is the metal aluminum?

47. A bar of silver has a mass of 68.0 g and a volume $6.48\ cm^3$. What is the density of silver?

Interactive Textbook

Problem-Solving 3.47 Solve Problem 47 with the help of an interactive guided tutorial.

with ChemASAP

SAMPLE PROBLEM 3.11

Using Density to Calculate Volume

What is the volume of a pure silver coin that has a mass of 14 g? The density of silver (Ag) is 10.5 g/cm^3.

1 Analyze ***List the knowns and the unknown.***

Knowns
- mass of coin = 14 g
- density of silver = 10.5 g/cm^3

Unknown
- volume of coin = ? cm^3

You can solve this problem by using density as a conversion factor. You need to convert the mass of the coin into a corresponding volume. The density gives the following relationship between volume and mass.

$$1\ \text{cm}^3\ \text{Ag} = 10.5\ \text{g Ag}$$

Based on this relationship, you can write the following conversion factor.

$$\frac{1\ \text{cm}^3\ \text{Ag}}{10.5\ \text{g Ag}}$$

Notice that the known unit is in the denominator and the unknown unit is in the numerator.

2 Calculate ***Solve for the unknown.***

Multiply the mass of the coin by the conversion factor to yield an answer in cm^3.

$$14\ \cancel{\text{g Ag}} \times \frac{1\ \text{cm}^3\ \text{Ag}}{10.5\ \cancel{\text{g Ag}}} = 1.3\ \text{cm}^3\ \text{Ag}$$

3 Evaluate ***Does the result make sense?***

Because a mass of 10.5 g of silver has a volume of 1 cm^3, it makes sense that 14.0 g of silver should have a volume slightly larger than 1 cm^3. The answer has two significant figures because the given mass has two significant figures.

Practice Problems

48. Use dimensional analysis and the given densities to make the following conversions.
- **a.** 14.8 g of boron to cm^3 of boron. The density of boron is 2.34 g/cm^3.
- **b.** 4.62 g of mercury to cm^3 of mercury. The density of mercury is 13.5 g/cm^3.

49. Rework the preceding problems by applying the following equation.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Math Handbook

For help with significant figures, go to page R59.

Interactive Textbook

Problem-Solving 3.48 Solve Problem 48 with the help of an interactive guided tutorial.

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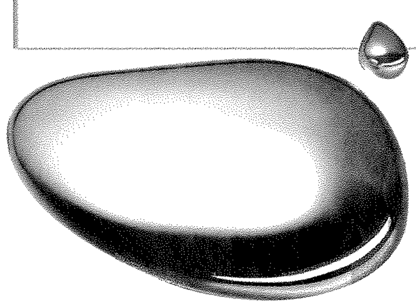
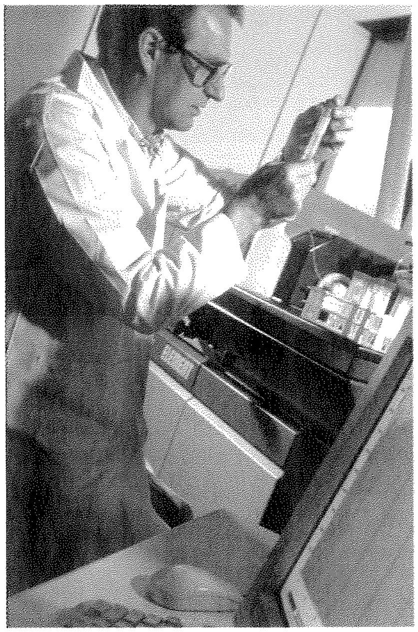


Mercury

Careers *in* Chemistry

Analytical Chemist



Analytical chemists focus on making quantitative measurements. They must be familiar with many analytical techniques to work successfully on a wide variety of tasks. As an analytical chemist, you would spend your time making measurements and calculations to solve laboratory and math-based research problems. You could, for example, be involved in analyzing the composition of biomolecules. Pharmaceutical companies need people to analyze the composition of medicines and research new combinations of compounds to use as drugs. As an analytical chemist, you must be able to think creatively and develop new means for finding solutions.

Many exciting new fields, such as biomedicine and biochemistry, are now hiring analytical chemists. More traditional areas, including industrial manufacturers, also employ analytical chemists. The educational background you need to enter this field is quite extensive. You would need advanced chemical training, including organic chemistry and quantitative chemistry, as well as some training in molecular biology and computer operation. A master's degree in chemistry may be required, and certain positions require a Ph.D.

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3.4 Section Assessment

50. **Key Concept** What determines the density of an object?

51. **Key Concept** How does density vary with temperature?

52. A weather balloon is inflated to a volume of 2.2×10^3 L with 37.4 g of helium. What is the density of helium in grams per liter?

53. A 68-g bar of gold is cut into 3 equal pieces. How does the density of each piece compare to the density of the original gold bar?

54. A plastic ball with a volume of 19.7 cm^3 has a mass of 15.8 g. Would this ball sink or float in a container of gasoline?

55. What is the volume, in cubic centimeters, of a sample of cough syrup that has a mass of 50.0 g? The density of cough syrup is 0.950 g/cm^3.

56. What is the mass, in kilograms, of 14.0 L of gasoline? (Assume that the density of gasoline is 0.680 g/cm^3.)

Elements Handbook

Density Look up the densities of the elements in Group 1A on page R6. Which Group 1A elements are less dense than pure water at 4°C?

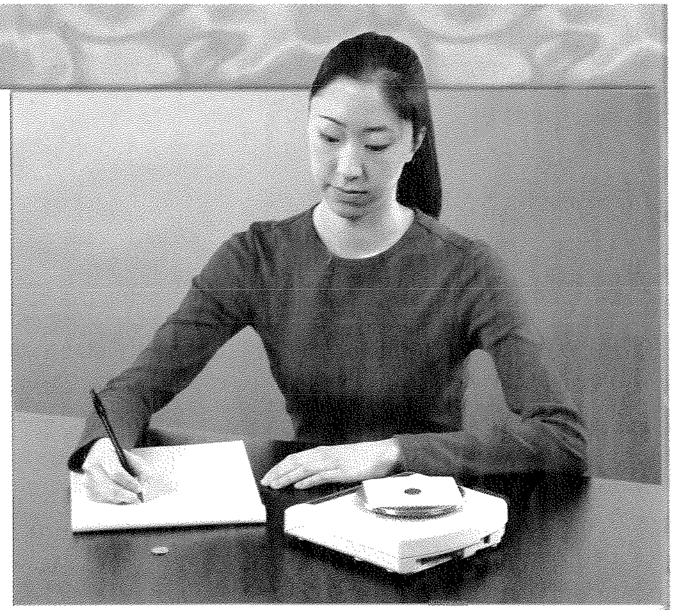
Interactive Textbook

Assessment 3.4 Test yourself on the concepts in Section 3.4.

with ChemASAP

Small-Scale LAB

Now What Do I Do?



Purpose

To solve problems by making accurate measurements and applying mathematics.

Materials

- pencil
- paper
- meter stick
- balance
- pair of dice
- aluminum can
- calculator
- small-scale pipet
- water
- a pre- and post-1982 penny
- 8-well strip
- plastic cup

Procedure

1. Determine the mass, in grams, of one drop of water. To do this, measure the mass of an empty cup. Add 50 drops of water from a small-scale pipet to the cup and measure its mass again. Subtract the mass of the empty cup from the mass of the cup with water in it. To determine the average mass in grams of a single drop, divide the mass of the water by the number of drops (50). Repeat this experiment until your results are consistent.
2. Determine the mass of a pre-1982 penny and a post-1982 penny.

Analyze

Using your experimental data, record the answers to the following questions.

1. What is the average mass of a single drop of water in milligrams? (1 g = 1000 mg)
2. The density of water is 1.00 g/cm^3. Calculate the volume of a single drop in cm^3 and mL. (1 mL = 1 cm^3) What is the volume of a drop in microliters (μL)? (1000 μL = 1 mL)
3. What is the density of water in units of mg/cm^3 and mg/mL? (1 g = 1000 mg)
4. Pennies made before 1982 consist of 95.0% copper and 5.0% zinc. Calculate the mass of copper and the mass of zinc in the pre-1982 penny.
5. Pennies made after 1982 are made of zinc with a thin copper coating. They are 97.6% zinc and 2.4% copper. Calculate the mass of copper and the mass of zinc in the newer penny.
6. Why does one penny have less mass than the other?

You're the Chemist

The following small-scale activities allow you to develop your own procedures and analyze the results.

1. **Design It!** Design an experiment to determine if the size of drops varies with the angle at which they are delivered from the pipet. Try vertical (90°), horizontal (0°), and halfway between (45°). Repeat until your results are consistent.
2. **Analyze It!** What is the best angle to hold a pipet for ease of use and consistency of measurement? Explain. Why is it important to expel the air bubbles before you begin the experiment?
3. **Design It!** Make the necessary measurements to determine the volume of aluminum used to make an aluminum soda can. *Hint:* Look up the density of aluminum in your textbook.
4. **Design It!** Design and carry out some experiments to determine the volume of liquid that an aluminum soda can will hold.
5. **Design It!** Measure a room and calculate the volume of air it contains. Estimate the percent error associated with not taking into account the furniture in the room.
6. **Design It!** Make the necessary measurements and do the necessary calculations to determine the volume of a pair of dice. First, ignore the volume of the dots on each face, and then account for the volume of the dots. What is your error and percent error when you ignore the holes?
7. **Design It!** Design an experiment to determine the volume of your body. Write down what measurements you would need to make and what calculations you would do. What additional information might be helpful?