Chapter 3 – Scientific Measurement

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Section 3.1 – Measurements and Their Uncertainty

- Many properties of matter at quantitative meaning they have a numerical value.
- A measurement is a quantity that has both a number and a unit.
- The unit typically used in the sciences are those of the International System of Measurements (SI).
- In scientific notation, a given number is written as the product of two numbers: a coefficient and 10 raised to a power.
- In scientific notation, the coefficient is always a number equal to or greater than one and less than ten.

6.5×10^{7}

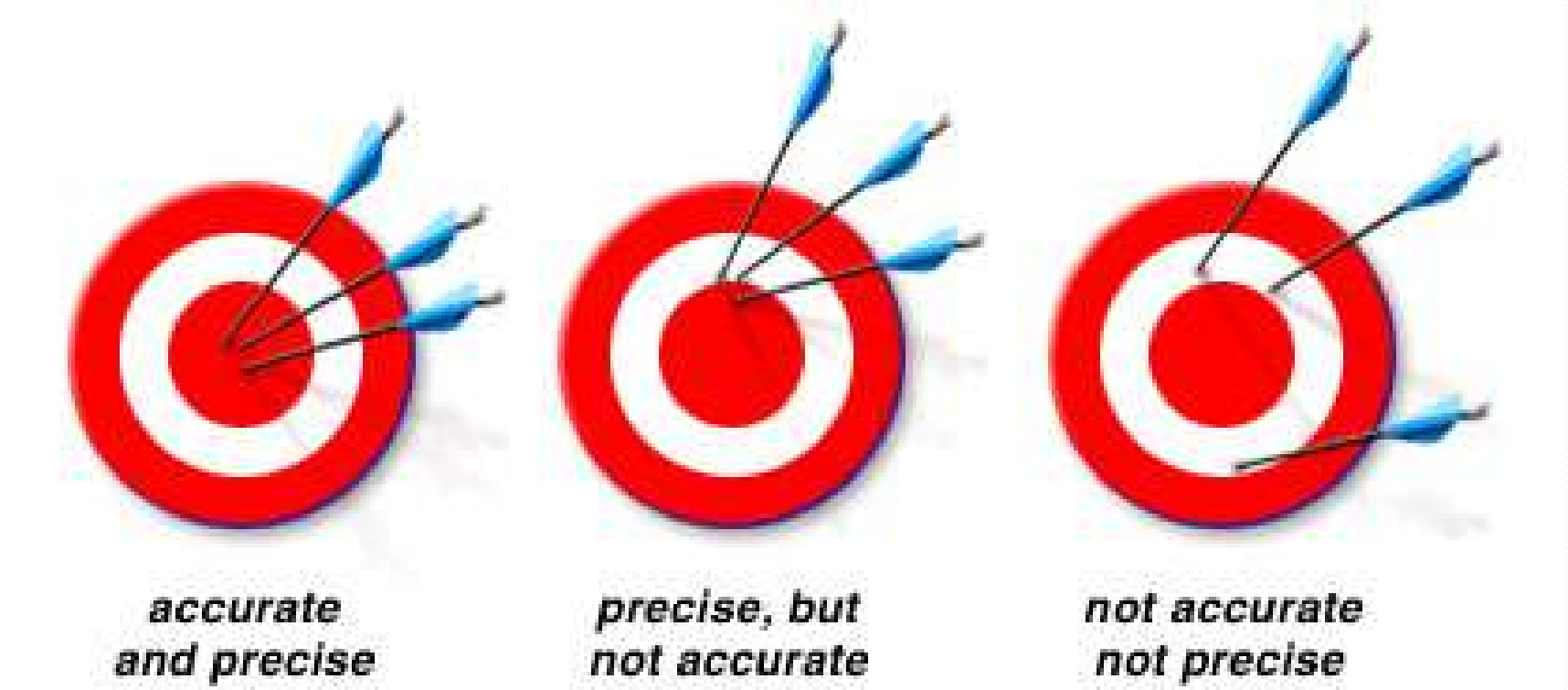
Sample Problems

- Write the following numbers in scientific notation:
  - 39400000
  - 2800
  - 0.000567
  - 0.0000002

- Write the following numbers in regular notation:
  - 3.22×10^{4}
  - 2.1×10^{-5}
  - 8×10^{2}
  - 7.90×10^{-6}

Accuracy vs. Precision

- Accuracy is a measure of how close a measurement comes to the actual or true value.
- Precision is a measure of how close a series of measurements are to one another.



Error

Error = experimental value – actual value

- The accepted value is the correct value.
- The experimental value is the value measured in the lab.
- The percent error is the absolute value of the error divided by the accepted value.

$$\text{Percent Error} = \frac{|\text{Error}|}{\text{Accepted value}} \times 100$$

So in other words,

$$\%E = \frac{|e - a|}{a} \times 100$$

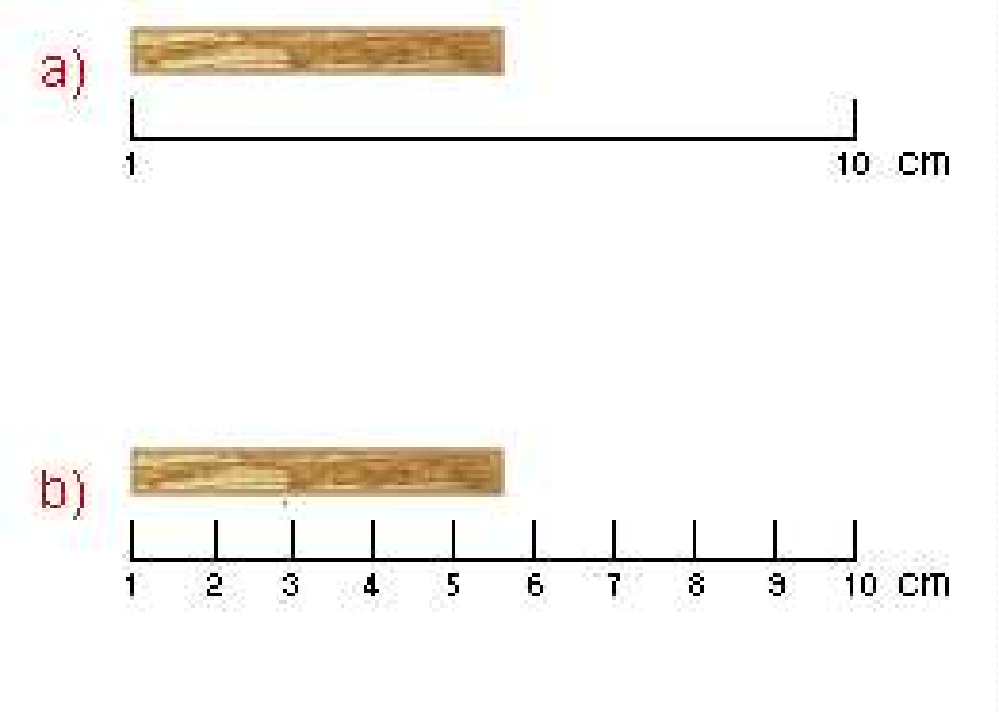
Sample Problem

- A block of aluminum has a mass of 147.3g. A student measures the mass of the block as 138.9g. What is the student's error?

- What is the percent error?

Significant Figures

- The significant figures in a measurement include all the digits that are known, plus a last digit that is estimated.



- The greater the number of significant figures, the greater the certainty implied for the measurement.

Rules for Significant Figures

- Every nonzero digit is significant. Ex: 254 or 65.43
- Zeros between significant figures are significant. Ex: 3005 or 1.083
- Zeros before (to the left) the significant figures are not significant. Ex: 0.07902 or 0.6932
- Zeros after (to the right) the significant figures are significant if the number contains a decimal point. Ex: 20.3200 or 63000 or 570. or 3.10×10^3
- Numbers that can be counted and conversion factors have an infinite number of significant figures. 370 crayons or 1km = 1000m (both have an infinite number of sig. figs.)

Sample Exercise

- How many significant figures are in each measurement?
  - a. 123 m
  - b. 4.003 m
  - c. 6.023×10^{23} atoms
  - d. 22 meter sticks
  - e. 0.07080 m
  - f. 5000 m
  - g. 170. kg

Practice Exercise

- How many significant figures are in each measurement?

  a. 0.05730 m

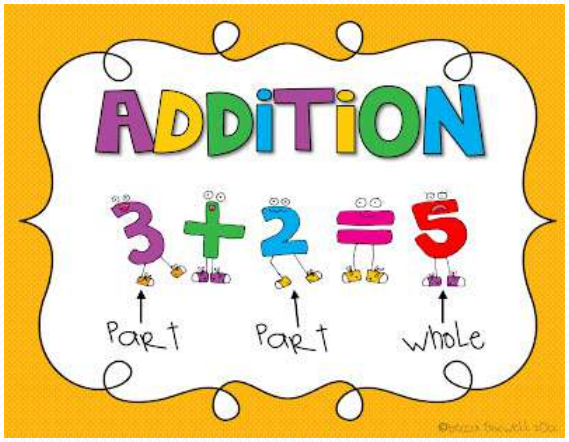
  b. 3.549 g

  c. 0.00134 m^3

  d. 2.3×10^4 cm

Significant Figures in Calculations

- In general, a calculated answer cannot be more precise than the least precise measurement from which it was calculated.
- When a calculation has multiple steps, you must check significant figures after each step.
- Addition and Subtraction
- When adding or subtracting, your answer can only have the same amount of decimal places as the number with the least amount of decimal places.



Sample Exercise

- Calculate the sum of the three measurements. Give the answer to the correct number of significant figures.

$$\begin{array}{r} 12.52\ \text{m} \\ 349.0\ \text{m} \\ +\ \ 8.24\ \text{m} \\ \hline \end{array}$$

Practice Exercise

- Perform each operation. Express your answers to the correct number of significant figures.

  a. 61.2 m + 9.35 m + 8.6 m =

  b. 34.61 m – 17.3 m =

Multiply and Divide

- When multiplying or dividing, your answer can only have the same amount of significant figures as the number with the lowest amount of significant figures.

Sample Exercise

- The width, length, and height of a small box are 15.5 cm, 27.3 cm, and 5.4 cm, respectively. Calculate the volume of the box, using the correct number of significant figures.

Practice Exercise

- Solve each problem and report your answer with the correct amount of significant figures.

- 2.10 m x 0.70 m =

- It takes 10.5 s for a sprinter to run 100.00 m. Calculate the average speed of the sprinter in meters per second, and express the result to the correct number of significant figures.

Sample Exercise

- A gas at 25°C fills a container whose volume is 1.05 x 10^3 cm^3. The container plus the gas have a mass of 837.6 g. The container, when emptied of all gas, has a mass of 836.2 g. What is the density of the gas at 25°C with the correct number of significant figures?

Practice Exercise

- To how many significant figures should the mass of the container be measured (with and without the gas) in the previous sample exercise for the density to be calculated to three significant figures?

Section 3.1 Assessment

1. How are accuracy and precision evaluated?

2. A technician experimentally determined the boiling point of octane to be 124.1°C. The actual boiling point of octane is 125.7°C. Calculate the error and the percent error.

3. Determine the number of significant figures in each of the following:

    a. 11 soccer players

    b. 0.070020 m

    c. 10800 m

    d. 5.00 m^3

Section 3.1 Assessment

4. Solve each of the following and express your answer with the correct number of significant figures.

a. 0.00072 x 1800 =

b. 0.912 – 0.047 =

c. 54000 x 3500000000 =

Section 3.2 – The International System of Units

- The International system of Units (SI) is a revised version of the metric system that scientists use around the world.

Quantity	SI Base Unit	Symbol
length	meter	m
mass	kilogram	kg
temperature	kelvin	K
time	second	s
amount of substance	mole	mol
luminous intensity	candela	cd
electric current	ampere	A

Prefixes

- Prefixes are used to show a very large or small quantity.
- For your prefixes sheet it is important to remember the following:

$$1 \text{ prefix unit} = 10^{x} \text{ base unit}$$

Example of Base Units	Example of Prefix Units
m	cm
L	mL
g	kg

Writing Conversion Factors

- Remember: 1 prefix unit = 10^x base unit

- Write the conversion factors for the following:
  a. cm → m
  b. g → kg
  c. s → ns
  d. dL → L

Derived Units

- Some units are a combination of SI base units. These are called derived units.

- Volume = length x width x height

  (m) (m) (m) = m^3

- Density = $\frac{\text{mass}}{\text{volume}}$ $\frac{(kg)}{(m^3)}$ = kg/m^3

Unit Declarations

```
unit N = kg m s^-2  repr

unit N2 = kg m s^-2  rep

unit Pa = N m^-2  repres

unit v = m s^-1  represe

unit a = m s^-2  represe
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Volumetric Glassware

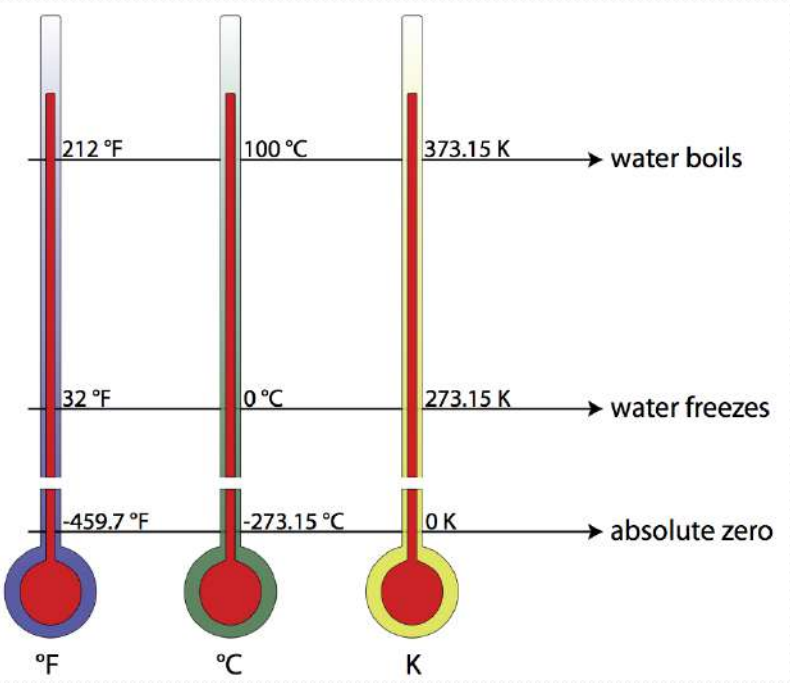
- Syringes, burets, and pipets deliver liquids with more precision than graduated cylinders.
- Volumetric flasks are used to contain specific volumes of liquids.
- Beakers and Erlenmeyer flasks should not be used to measure volume because they lack precision.

Mass vs. Weight

- Mass is the amount of matter that an object contains. The SI unit is kilograms.
- Weight is the force that measures the pull of gravity on a given mass. The SI unit is Newtons.
- Since weight is based on gravity, it changes with location.
- Mass stays constant regardless of location.

Temperature

- Temperature is a measure of how hot or cold an object is. (It is the measure of the average kinetic energy of an object's particles)
- Heat always flows spontaneously from a substance at a higher temperature to one at a lower temperature.
- There are 3 temperature scales that are used: Celsius, Fahrenheit, and Kelvin.



Absolute Zero

- Absolute zero is zero on the Kelvin scale.
- Kelvin temperature is directly proportional to the kinetic energy (speed) of the particles.
- If the particles are not moving, then the Kelvin temperature is zero.
- Since the particles cannot go slower than stopped, then the Kelvin scale does not have any negative values.

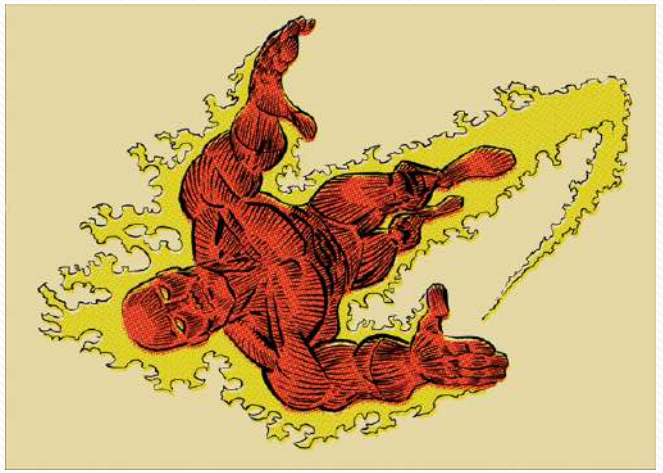
Converting Temperatures

- The following formulas are used to convert between temperatures:

- $K = {}^\circ C + 273$
- ${}^\circ C = K - 273$

$${}^\circ C = 5/9({}^\circ F - 32)$$

$${}^\circ F = 9/5({}^\circ C) + 32$$



Sample Exercise

- If a weather forecaster predicts that the temperature for the day will reach 31°C, what is the predicted temperature in
  a. Kelvin

  b. Fahrenheit

Practice Exercise

Ethylene glycol, the major ingredient in antifreeze, freezes at -11.5 °C. What is the freezing point in

a. Kelvin

b. Farhenheit

Convert 56 °F to K.

Energy

- Energy is the ability to do work or supply heat.
- The SI unit of energy is the Joule (J).
- In America, we use calories instead of Joules.

1 cal = 4.184J

Section 3.2 Assessment

1. What are the SI units for the 5 common base units used in Chemistry?

2. What is the symbol and meaning for each prefix?

    a. milli-

    b. nano-

    c. deci-

    d. centi-

3. List the following units in order from largest to smallest: mL, cL, µL, L, dL.

4. What is the volume of a paperback book 21 cm tall, 12 cm wide, and 3.5 cm thick?

Section 3.2 Assessment

5. State the difference between weight and mass.
6. Convert 170°C to kelvin.
7. State the relationship between joules and calories.

Section 3.3 – Conversion Problems

- A conversion factor is a ratio of two equivalent measurements.
- Whenever two measurements are equivalent, then the ratio equals 1.

$$12 \text{ in} = 1 \text{ ft} \quad \text{or} \quad 1 \text{ ft} = 12 \text{ in}$$

- Ratio form:

$$\frac{12 \text{ in}}{1 \text{ ft}} \quad \text{or} \quad \frac{1 \text{ ft}}{12 \text{ in}}$$

Dimensional Analysis

- Dimensional analysis is a way to analyze and solve problems using the units of the measurements.
- Some conversion factors that you should be familiar with involve time:

1 min = 60 s

60 min = 1 hr

24 hr = 1 day

365 days = 1 yr

3600s = 1 hr

Sample Problem

- How many seconds are in a workday that lasts exactly eight hours?

Practice Problems

- How many minutes are there in exactly 1 week?
- How many seconds are in exactly 40 hours?
- How many years is 895600000 s?

Sample Problem

- Convert 750 dg to grams.

- What is the name given to the unit that equals
  a. 10^{-9} gram
  b. 10^{-6} second
  c. 10^{-3} meter

Practice Problems

- Convert 0.044 km to meters.

- Convert 6.7 s to milliseconds.

Practice Problem

- What decimal fraction of a second is a picosecond?
- Express the measurement 6.0×10^3 m using a prefix to replace the power of ten.
- Use exponential notation to express 3.76 mg to grams.

Sample Problem

- What is 0.073 cm in micrometers?

Practice Problems

- Convert 0.227 nm to centimeters.
- Convert 1.3×10^4 km to decimeters.
- Convert 1325 dag to megagrams.

Sample Problem

- The average speed of a nitrogen molecule in air at 25°C is 515 m/s. Convert this speed to miles per hour. (Hint: 5 km = 3.1 mi)

- A car travels 28 miles per gallon of gasoline. How many kilometers per liter will it go? (Hint: 1 gal = 3.7854 L)

Practice Problems

- Convert 90 km/hr to m/s.

- Convert 78 hg/μL to g/L.

Sample Problem

- Earth's oceans contain approximately 1.36×10^9 km^3 of water. Calculate the volume in liters. (Hint: 1 mL = 1 cm^3)

Practice Problems

- If the volume of an object is reported as 5.0 ft^3, what is the volume in cubic meters? (Hint: 1 in = 2.54 cm)

- Convert 50 m/s^2 to km/hr^2.

Other Conversion Factors

- Here is a list of other conversion factors that you need to memorize:

1 in. = 2.54 cm

1 kg = 2.2 lbs.

1 cm^3 = 1 mL

1 cal = 4.184 J

- Density can be used as a conversion factor between mass and volume.

Sample Problem

- If a woman has a mass of 115 lb, what is her mass in grams?

Practice Problems

- Convert 250 cal into joules.
- Convert 50 cm^3 into liters.
- Convert 25 m into feet.

Section 3.3 Assessment

1. What conversion factor would you use to convert between these pairs of units?

   a. minutes to hours

   b. grams to milligrams

   c. cubic decimeters to milliliters

2. Make the following conversions:

   a. 14.8 g to micrograms

   b. 3.72×10^{-3} kg to grams

   c. 66.3 L to cubic centimeters

Section 3.3 Assessment

3. An atom of gold has a mass of 3.271×10^{-23} g. How many atoms of gold are in 5.00 g of gold?

4. Convert the following:

   a. 7.5×10^{4} J to kilojoules

   b. 3.9×10^{5} mg to decigrams

   c. 2.21×10^{-4} dL to microliters

Section 3.3 Assessment

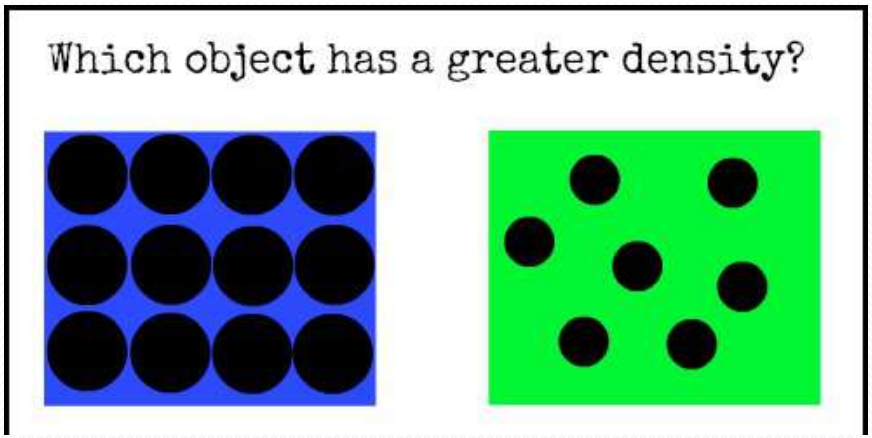
5. Light travels at a speed of 3.00×10^{10} cm/s. What is the speed of light in kilometers per hour?

Section 3.4 - Density

- Density is the ratio of the mass of an object to its volume.

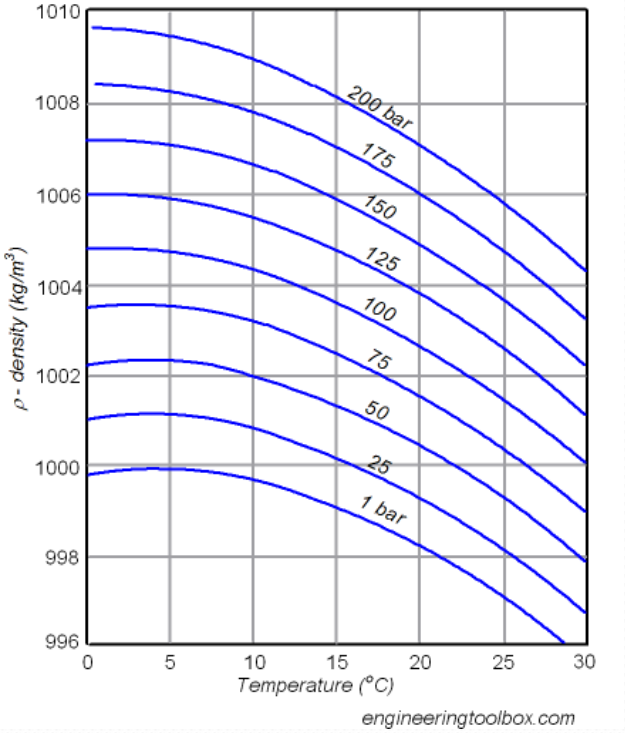
$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

- Density is an intensive property that depends only on the composition of a substance, not on the size of the sample.
- The density of water is 1 g/mL.



Density and Temperature

- Because most substances change volume when they are heated or cooled, densities are temperature dependent.
- The density of a substance generally decreases as its temperature increases.
- Water is an exception to this rule.



Sample Problem

- Calculate the density of mercury if 1.00×10^2 g occupies a volume of 7.36 cm^3?

- Calculate the volume of 65.0 g of the liquid methanol (wood alcohol) if its density is 0.791 g/mL.

- What is the mass in grams of a cube of gold (density = 19.32 g/cm^3) if the length of the cube is 2.00 cm?

Practice Problems

- Calculate the density of a 374.5 g sample of copper if it has a volume of 41.8 cm^3.

- A student needs 15.0 g of ethanol for an experiment. If the density of ethanol is 0.789 g/mL, how many milliliters of ethanol are needed?

- What is the mass, in grams, of 25.0 mL of mercury (density = 13.6 g/mL)?

Section 3.4 Assessment

1. What determines the density of an object?
2. How does density vary with temperature?
3. 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?

4. 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?
5. 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? (Density of gasoline = 0.675 g/cm^3)

Section 3.4 Assessment

6. 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.

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