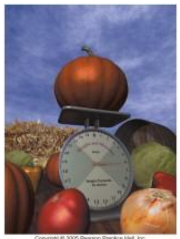
Introductory Chemistry, 2nd Edition
Nivaldo Tro



Chapter 2 Measurement and Problem Solving

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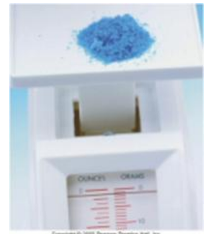
2.1 What is a Measurement?

- quantitative observation
- comparison to an agreed upon standard
- every measurement has a <u>number and a unit</u>



A Measurement

- the unit tells you what quantity is being measured
- the number tells you
  1. what multiple of the standard the object measures
  2. the uncertainty in the measurement

Scientists have measured the average global temperature rise over the past century to be **0.6°C**

- **°C** tells you that the temperature is being compared to the Celsius temperature scale
- **0.6** tells you that
  1. the average temperature rise is 0.6 times the standard unit
  2. the uncertainty in the measurement is such that we know the measurement is between 0.5 and 0.7°C

2.2 Scientific Notation

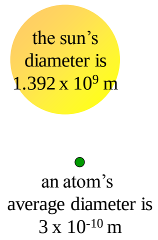
A way of writing large and small numbers

Big and Small Numbers

the sun's diameter is 1,392,000,000 m

an atom's average diameter is 0.000 000 000 3 m

Scientific Notation



Scientific Notation

- Consists of a decimal value and exponent
- The decimal value is called the <u>coefficient</u>

<u>coefficient</u> <u>exponent</u>

3×10^{-23}

Coefficients

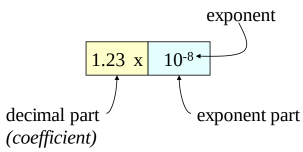
- The decimal value in a scientic notation number
- This must be between 1→9.999 (<10)
- sun's diameter = 1.392×10^9 m

Exponents

- *The power 10 is raised to…e.g.* $\times 10^9$
- when the exponent on 10 is positive, it means the number is that many powers of 10 larger
  - ✓sun's diameter = 1.392×10^9 m = 1,392,000,000 m
- when the exponent on 10 is negative, it means the number is that many powers of 10 smaller
  - ✓avg. atom's diameter = 3×10^{-10} m = 0.0000000003 m

Scientific Notation

- To Compare Numbers Written in Scientific Notation
  - ✓First Compare Exponents on 10
  - ✓If Exponents Equal, Then Compare Decimal Numbers



$1.23 \times 10^5 > 4.56 \times 10^2$

$4.56 \times 10^{-2} > 7.89 \times 10^{-5}$

$7.89 \times 10^{10} > 1.23 \times 10^{10}$

Writing a Number In Scientific Notation

1 Locate the Decimal Point

2 Move the decimal point until the number (*the coefficient*) is greater than one and less than 10

3 Multiply the new number by 10^n
  - ✓where ***n*** is the number of places you moved the decimal pt.

4 if the number is ≥ 1, ***n*** is +; if the number is < 1, ***n*** is -

Writing a Number In Scientific Notation

12340

1 Locate the Decimal Point

12340.

2 Move the decimal point until the number (*the coefficient*) is greater than one and less than 10

1.234

3 Multiply the new number by 10^n

✓ where ***n*** is the number of places you moved the decimal pt.

1.234×10^4

4 if the number is ≥ 1, ***n*** is +; if the number is < 1, ***n*** is -

1.234×10^4

Writing a Number In Scientific Notation

4.1340

1 Locate the Decimal Point

4.1340

2 Move the decimal point until the number (*the coefficient*) is greater than one and less than 10

4.1340

3 Multiply the new number by 10^n

✓ where ***n*** is the number of places you moved the decimal pt.

4.1340×10^0

4 if the number is ≥ 1, ***n*** is +; if the number is < 1, ***n*** is -

4.1340×10^0

Writing Numbers in Scientific Notation

0.00012340

1 Locate the Decimal Point 0.00012340

2 Move the decimal point until the number (*the coefficient*) is greater than one and less than 10. 1.2340

3 Multiply the new number by 10^n

✓ where ***n*** is the number of places you moved the decimal point 1.2340×10^4

4 if the original number is ~~≥ 1, ***n*** is +~~; if the number is < 1, ***n*** is - 1.2340×10^{-4}

Writing a Number in Standard Form

1.234×10^{-6}

- since exponent is -6, make the number smaller by moving the decimal point to the left 6 places
  - ✓if you run out of digits, add zeros

000 001,234

0.000 001 234

Inputting Scientific Notation into a Calculator

-1.23×10^{-3}

Action	Key	Display
Input 1.23		1.23
Press	"+/-" or "–"	-1.23
Press	EXP or EE	-1.23 00
Input 3		-1.23 03
Press	"+/-" or "–"	-1.23 -03

Try this…..

2.3 Significant Figures

Writing Numbers to Reflect Precision

Exact Numbers vs. Measurements

- counting numbers are EXACT
  - pennies in a pile
- sometimes defined numbers are EXACT
  - 1 ounce is exactly 1/16th of 1 pound
- Measured numbers always contain uncertainty

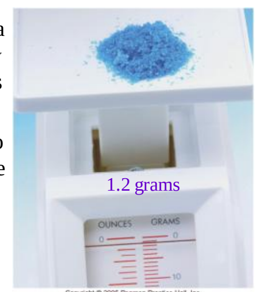
Reporting Measurements

- measurements are written to indicate the uncertainty in the measurement
- the system of writing measurements we use is called **significant figures**
- when writing measurements, all the digits written are known with certainty except the last one, which is an estimate

45.872 — certain: 45.87; estimated: 2

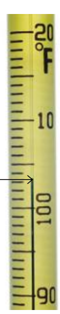
Estimating the Last Digit

- for instruments marked with a scale, you get the last digit by estimating between the marks
  - ✓ if possible
- mentally divide the space into 10 equal spaces, then estimate how many spaces over the indicator is



Skillbuilder 2.3 – Reporting the Right Number of Digits

- What is the temperature reading to the correct number of digits?



Counting Significant Figures

- All non-zero digits are significant
  - ✓1.5 has 2 sig. figs.
- Interior zeros are significant
  - ✓1.05 has 3 sig. figs.
- Trailing zeros after a decimal point are significant
  - ✓1.050 has 4 sig. figs.

Counting Significant Figures

4. Leading zeros are **NOT** significant
   - ✓ 0.001050 has 4 sig. figs.
     - 1.050×10^{-3}
5. Zeros at the end of a number without a written decimal point are ambiguous and should be avoided by using scientific notation
   - ✓ if 150 has 2 sig. figs. then 1.5×10^{2}
   - ✓ but if 150 has 3 sig. figs. then 1.50×10^{2}

Significant Figures and Exact Numbers

- Exact Numbers have an unlimited number of significant figures
- A number whose value is known with complete certainty is **exact**
  - ✓from counting individual objects
  - ✓from definitions
    - 1 cm is exactly equal to 0.01 m
  - ✓from integer values in equations
    - in the equation for the radius of a circle, the 2 is exact

$$\text{radius of a circle} = \frac{\text{diameter of a circle}}{2}$$

Example 2.4 – Determining the Number of Significant Figures in a Number

- How many significant figures are in each of the following numbers?

0.0035

1.080

2371

2.97 10^{5}

1 dozen = 12

100,000

2.4 Significant Figures in Calculations

When multiplying or dividing measurements with significant figures, the answer is

"ROUNDED"

to the same number of significant figures as the measurement with the fewest number of significant figures

Rounding

When rounding to the correct number of significant figures,

- if the number after the last significant figure is:

<u>0 to 4, round down</u>

- ✓ drop all digits after the last sig. fig. and leave the last sig. fig. alone
- ✓ add insignificant zeros to <u>keep the value</u> if necessary

<u>5 to 9, round up</u>

- ✓ drop all digits after the last sig. fig. and increase the last sig. fig. by one
- ✓ add insignificant zeros to keep the value if necessary

<u>Rounding</u>

Rounding to 2 significant figures:

- 2.34 rounds to 2.3
  - ✓because the 3 is where the last sig. fig. will be and the number after it is 4 or less
- 2.37 rounds to 2.4
  - ✓because the 3 is where the last sig. fig. will be and the number after it is 5 or greater

Rounding

Rounding to 2 significant figures

- 234 rounds to 230 or 2.3 10^2
  - ✓because the 3 is where the last sig. fig. will be and the number after it is 4 or less
- 237 rounds to 240 or 2.4 10^2
  - ✓because the 3 is where the last sig. fig. will be and the number after it is 5 or greater

Multiplication and Division with Significant Figures

- when multiplying or dividing measurements with significant figures, the answer has the same number of significant figures as the measurement with the fewest number of significant figures

5.02 89,665 0.10 = 45.0118 = **45**

3 sig. figs. 5 sig. figs. 2 sig. figs. → 2 sig. figs.

5.892 6.10 = 0.96590 = 0.966

4 sig. figs. 3 sig. figs.

Determine the Correct Number of Significant Figures for each Calculation and Round and Report the Result

1. 1.01 0.12 53.51 96 =
2. 56.55 0.920 34.2585 =

Addition and Subtraction with Significant Figures

When adding or subtracting measurements with significant figures, the result has the same number of decimal places as the measurement with the fewest number of decimal places

5.74 + 0.823 + 2.651 = 9.214 = 9.21

2 dec. pl. 3 dec. pl. 3 dec. pl. 2 dec. pl.

4.8 - 3.965 = 0.835 = 0.8

1 dec. pl 3 dec. pl. 1 dec. pl.

Determine the Correct Number of Significant Figures for each Calculation and Round and Report the Result

1. 0.987 + 125.1 – 1.22 =
2. 0.764 – 3.449 – 5.98 =

Both Multiplication/Division and Addition/Subtraction with Significant Figures

When doing different kinds of operations with measurements with significant figures, do whatever is in parentheses first, find the number of significant figures in the intermediate answer, then do the remaining steps

3.489 (5.67 – 2.3) =

2 dp 1 dp

3.489 3.<u>3</u>7 = 12

4 sf 1 dp & 2 sf 2 sf

2.5 Basic Units of Measure

The Standard Units

- Scientists have agreed on a set of international standard units for comparing all our measurements called the SI units
  - ✓ *Système International* = International System

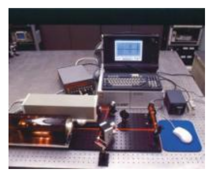
Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K

Some Base Units in the Metric System

Quantity Measured	Name of Unit	Abbreviation
Mass	gram	g
Length	meter	m
Volume	liter	L
Time	seconds	s
Temperature	Kelvin	K

Length

- Measure of the two-dimensional distance an object covers
- SI unit = meter
  - ✓ About 3½ inches longer than a yard
    - 1 meter = one ten-millionth the distance from the North Pole to the Equator = distance between marks on standard metal rod in a Paris vault = distance covered by a certain number of wavelengths of a special color of light
- Commonly use centimeters (cm)
  - ✓ 1 m = 100 cm
  - ✓ 1 cm = 0.01 m = 10 mm
  - ✓ 1 inch = 2.54 cm (exactly)

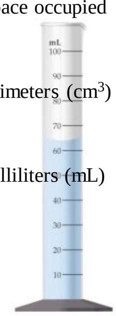


Mass

- Measure of the amount of matter present in an object
- SI unit = kilogram (kg)
  - ✓ about 2 lbs. 3 oz.
- Commonly measure mass in grams (g) or milligrams (mg)
  - ✓ 1 kg = 2.2046 pounds, 1 lbs. = 453.59 g
  - ✓ 1 kg = 1000 g = 10^3 g,
  - ✓ 1 g = 1000 mg = 10^3 mg
  - ✓ 1 g = 0.001 kg = 10^{-3} kg,
  - ✓ 1 mg = 0.001 g = 10^{-3} g

Volume

- Measure of the amount of three-dimensional space occupied
- SI unit = cubic meter (m^3)
  - ✓ a Derived Unit
- Commonly measure solid volume in cubic centimeters (cm^3)
  - ✓ 1 m^3 = 10^6 cm^3
  - ✓ 1 cm^3 = 10^{-6} m^3 = 0.000001 m^3
- Commonly measure liquid or gas volume in milliliters (mL)
  - ✓ 1 L is slightly larger than 1 quart
  - ✓ 1 L = 1 dL^3 = 1000 mL = 10^3 mL
  - ✓ 1 mL = 0.001 L = 10^{-3} L
  - ✓ 1 mL = 1 cm^3



Related Units in the SI System

- All units in the SI system are related to the standard unit by a power of 10
- The power of 10 is indicated by a prefix
- The prefixes are always the same, regardless of the standard unit

Common Prefixes in the SI System

Prefix	Symbol	Decimal Equivalent	Power of 10
mega-	M	1,000,000	Base x 10^{6}
kilo-	k	1,000	Base x 10^{3}
deci-	d	0.1	Base x 10^{-1}
centi-	c	0.01	Base x 10^{-2}
milli-	m	0.001	Base x 10^{-3}
micro-	µ or mc	0.000 001	Base x 10^{-6}
nano-	n	0.000 000 001	Base x 10^{-9}

2.6 Problem Solving and Dimensional Analysis

Units

- Always write every number with its associated unit
- Always include units in your calculations
  - ✓you can do the same kind of operations on units as you can with numbers
    - cm cm = cm^2
    - cm + cm = cm
    - cm cm = 1
  - ✓using units as a guide to problem solving is called ***dimensional analysis***

Conversion Factors and Dimensional Analysis

- Many problems in Chemistry involve using relationships to convert one unit of measurement to another
- Conversion Factors are relationships between two units
  - ✓May be exact or measured
  - ✓Both parts of the conversion factor have the same number of significant figures

Conversion Factors and Dimensional Analysis

- Conversion factors generated from equivalence statements
  - ✓e.g. 1 inch = 2.54 cm can give or

$$\frac{2.54\text{cm}}{1\text{in}} \qquad \frac{1\text{in}}{2.54\text{cm}}$$

The method…

- Arrange conversion factors so starting unit cancels
  - ✓ Arrange conversion factor so starting unit is on the bottom of the conversion factor
- May string conversion factors
  - ✓ So we do not need to know every relationship, as long as we can find something else the beginning and ending units are related to

$$\text{unit 1} \times \frac{\textbf{unit 2}}{\textbf{unit 1}} = \text{unit 2}$$

Systematic Approach

1) Write down Given Amount and Unit
2) Write down what you want to Find and Unit
3) Write down needed Conversion Factors or Equations
4) Write solution map
5) Apply the steps in the solution map
6) Check the answer to see if it is reasonable

Solution Maps

- a solution map is a visual outline that shows the strategic route required to solve a problem
- for unit conversion, the solution map focuses on units and how to convert one to another
- for problems that require equations, the solution map focuses on solving the equation to find an unknown value

Solution Maps and Conversion Factors

- Convert Inches into Centimeters
  1) Find Relationship Equivalence: 1 in = 2.54 cm
  2) Write Solution Map

     in → cm

  3) Change Equivalence into Conversion Factors with Starting Units on the Bottom

$$\frac{2.54\ \text{cm}}{1\ \text{in}}$$

A baseball has a diameter of 2.90457771 inches. How many centimeters is this?

2.7 Multistep Conversions

- Convert Cups into Liters
  1) Find Relationship Equivalence: 1 L = 1.057 qt, 1 qt = 4 c
  2) Write Solution Map

     c → qt → L

  3) Change Equivalence into Conversion Factors with Starting Units on the Bottom

$$\frac{1\ \text{qt}}{4\ \text{c}} \qquad \frac{1\text{L}}{1.057\ \text{qt}}$$

How many liters are there in a container that has a volume of 16 cups?

2.8 Units Raised to a Power

- Convert Cubic Inches into Cubic Centimeters
  1) Find Relationship Equivalence: 1 in = 2.54 cm
  2) Write Solution Map

$in^3 \longrightarrow cm^3$

  3) Change Equivalence into Conversion Factors with Starting Units on the Bottom

$$\left(\frac{2.54\ cm}{1\ in}\right)^3 = \frac{2.54^3\ cm^3}{1^3\ in^3} = \frac{16.4\ cm^3}{1\ in^3}$$

How many cubic centimeters are there in a fish tank that has a volume of 555 cubic inches?

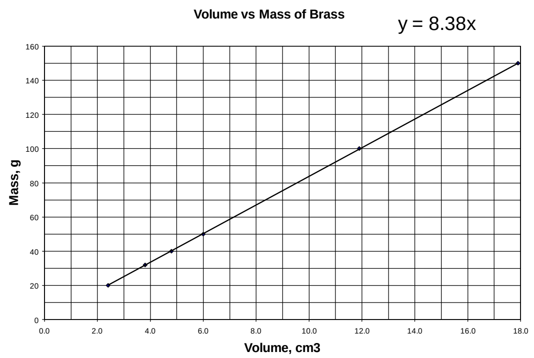
2.9 Density

Mass & Volume

- two main characteristics of matter
- even though mass and volume are individual properties - for a given type of matter they are related to each other!

Mass vs Volume of Brass

Mass grams	**Volume cm^3**
20	2.4
32	3.8
40	4.8
50	6.0
100	11.9
150	17.9



Density

Ratio of mass:volume

$$Density = \frac{Mass}{Volume}$$

Density (cont.)

- For equal volumes, denser object has larger mass
- For equal masses, denser object has smaller volume
- Heating objects causes objects to expand
  - ✓does not effect their mass!!
  - ✓How would heating an object effect its density?
- In a heterogeneous mixture, the denser object sinks
  - ✓Why do hot air balloons rise?

Using Density in Calculations

Solution Maps:

$$Density = \frac{Mass}{Volume}$$ m, V → D

$$Volume = \frac{Mass}{Density}$$ m, D → V

$$Mass = Density \times Volume$$ V, D → m

She places the ring on a balance and finds it has a mass of 5.84 grams. She then finds that the ring displaces 0.556 cm³ of water. Is the ring made of platinum? (Density Pt = 21.4 g/cm³)

Given: Mass = 5.84 grams

Volume = 0.556 cm³

Find: Density in grams/cm³

Equation: $\frac{m}{V} = D$

Solution Map:

m* and *V* → *d

m, V → d

$$d = \frac{m}{V}$$

Density as a Conversion Factor

- **can use density as a conversion factor between mass and volume!!**
  - ✓density of H_2O = 1 g/mL ∴ 1 g H_2O = 1 mL H_2O
  - ✓density of Pb = 11.3 g/cm³ ∴ 11.3 g Pb = 1 cm³ Pb
- What is the volume of 50.0 lb of lead?
- How much does 4.0 cm³ of Lead weigh?

Measurement and Problem Solving
Density as a Conversion Factor

- The gasoline in an automobile gas tank has a mass of 60.0 kg and a density of 0.752 g/cm^3. What is the volume?
- Given: 60.0 kg
- Find: Volume in L
- Conversion Factors:
  - ✓0.752 grams/cm^3
  - ✓1000 grams = 1 kg