Module 1: Measurement and Units

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1 Overview

1. **Matter** is anything that has *mass* and takes up space
2. **Units of Measurement** make numbers meaningful
3. **The Metric System** is designed to make units measurement consistent and simple
4. **Unit Conversion** is based on multiplying fractions
5. **Significant Figures** are a convention for maintaining precision in measurements
6. **Scientific Notation** allows us to represent numbers "naturally"
7. **Density** is a measure of how tightly mass is packed into volume

2 The Metric System

The metric system is an attempt to make measurements more standardized and easier to use in mathematical equations than our "English" or "Imperial" system.

- each physical quantity has a *base unit* for that quantity [Wile, 2003, p. 5] (see Table 1, page 5)
- each base unit can be scaled up or down through *metric prefixes* that represent powers of 10 [Wile, 2003, p. 7] (see Table 2, page 5)
- note: don't make the mistake of thinking that *mass* and *weight* are the same thing[1]

[1] *Mass* is how much of you there is, *weight* is how hard gravity pulls you down. In a constant gravitational field (*e.g.* most places on earth), weight is a useful proxy for mass, but don't let's get them confused.

3 Significant Figures

- we need a way to communicate uncertainty in our measurements
- any number we record contains its own precision claims
- when we record any measurements, we need to be careful of our significant figures

3.1 Rules for Significant Figures

Per our textbook [Wile, 2003, p. 21], a digit is a significant figure if:

1. it is non-zero, or
2. it is a zero between two significant figures, or
3. it is a zero to the right of a decimal point

3.2 Examples

Example 1 2.80 has three significant figures

Example 2 0.0028 has two significant figures

Example 3 28000 has two significant figures

Example 4 5.56 has three significant figures

Example 5 0.44 has two significant figures

3.3 Mathing with Significant Figures

- when adding or subtracting, round your answer to the same precision as your least precise measurement ([Wile, 2003, p. 25])
- when multiplying or dividing, round your answer to the same number of significant figures as your least precise measurement ([Wile, 2003, p. 26])
- digits in fractions don't count: ignore them!
- digits in definitions are considered to have infinite precision, so we can safely ignore them

3.4 Examples

Example 1 What is $5.56mm + 9mm$?

$$\boxed{\begin{aligned} 5.56mm + 9mm &= 14.56mm \\ &= 15mm \end{aligned}} \tag{1}$$

Example 2 What is $2.80cm + 3.6678cm$?

$$\boxed{\begin{aligned} 2.80cm + 3.6678cm &= 6.4678cm \\ &= 6.47cm \end{aligned}} \tag{2}$$

Example 3 What is $17.000ft \times 3.001lb$?

$$\boxed{\begin{aligned} 17.000ft \times 3.001lb &= 51.017ft \cdot lb \\ &= 51.02ft \cdot lb \end{aligned}} \tag{3}$$

Example 4 What is $5.243mol \div 17.32543L$?

$$\boxed{\begin{aligned} 5.243mol \div 17.32543L &= \frac{5.243mol}{17.32543L} \\ &= 0.30261875\frac{mol}{L} \\ &= 0.3026\frac{mol}{L} \end{aligned}} \tag{4}$$

4 Scientific Notation

- we can represent numbers as a number $\{x|1 \leq x < 10\}$ multiplied by a power of 10
- this is particularly helpful with very large or very small numbers.
- the rules for scientific notation are:
  1. the first number is between 1 and 10
  2. the power of 10 is the number of places you move the decimal on the original number to the *left* (*e.g.* 1000 is 10^3) [2]

[2] "Left" and "right" here get tricky: we're counting spaces we need to move the decimal *of the original number* in order to get something between 1 (inclusive) and 10 (exclusive).

3. if you move the decimal to the *right*, then the power of 10 is negative (*e.g.* 0.01 is 10^{-2})

- notice that it's very easy to track significant figures with scientific notation!
- notice that the metric system is just scientific notation with pretentious names! (see Table 3, page 5)

4.1 Examples

Example 1 we can write 1000 as 1×10^3

Example 2 we can write 256 as 2.56×10^2

Example 3 we can write 0.000002341 as 2.341×10^{-6}

5 Unit Conversion

- we use the idea of fraction multiplication to convert measurements between units.
- **we can multiply any number by 1 without changing it!**

5.1 Examples

Example 1 How many yards in a mile?

We begin with what we know:

- $1mile = 5280ft$
- $1yd = 3ft$

Metric Base Unit	Physical Quantity	Approximate Size
meter	length	just over 1 yard (39.37 inches)
gram	mass	one penny is about 2 grams
liter	volume	just over 1 quart
second	time	about 1 second

Table 1: Common metric base units

Metric Prefix	Power of 10
giga (G)	$1,000,000,000$
mega (M)	$1,000,000$
kilo (k)	$1,000$
hecta (H)	100
deca (D)	10
deci (d)	0.1
centi (c)	0.01
milli (m)	0.001
micro (μ)	0.000001
nano (n)	0.000000001

Table 2: Most common metric prefixes

Pretentious Name	Scientific Notation Equivalent
giga (G)	$\times 10^9$
mega (M)	$\times 10^6$
kilo (k)	$\times 10^3$
hecta (H)	$\times 10^2$
deca (D)	$\times 10^1$
deci (d)	$\times 10^{-1}$
centi (c)	$\times 10^{-2}$
milli (m)	$\times 10^{-3}$
micro (μ)	$\times 10^{-6}$
nano (n)	$\times 10^{-9}$

Table 3: Scientific Notation and Metric Prefixes

$$\boxed{\begin{aligned} 1mile &= (\frac{1mile}{1})(\frac{5280ft}{1mile})(\frac{1yd}{3ft}) \\ &= \frac{(1\cancel{mile})(5280\cancel{ft})(1yd)}{(1\cancel{mile})(3\cancel{ft})} \\ &= \frac{5280yd}{3} \\ &= \frac{5280}{3}yd \\ &= 1760yd \end{aligned}} \tag{5}$$

Example 2 How many cups are in 5 liters?

We begin with what we know:

- $1quart = 2pints$
- $1pint = 2cups$
- $1quart = 0.946353L$

$$
\boxed{\begin{aligned}
5L &= (\frac{5L}{1})(\frac{1qt}{0.946353L})(\frac{2pint}{1qt})(\frac{2cup}{1pint}) \\
&= (\frac{5\cancel{L}}{1})(\frac{1\cancel{qt}}{0.946353\cancel{L}})(\frac{2\cancel{pint}}{1\cancel{qt}})(\frac{2cup}{1\cancel{pint}}) \\
&= \frac{5 \cdot 2 \cdot 2cup}{0.946353} \\
&= \frac{5 \cdot 4 \cdot 2}{0.946353}cup \\
&= \frac{20}{0.946353}cup \\
&= 21.1338cup
\end{aligned}} \tag{6}
$$

6 Density

1. density is a measurement of how tightly packed matter is in an object
2. it's related to both *mass* (how much matter there is) and *volume* (how much space something takes up)
3. when you pick up an object and think, "it didn't look that heavy," you're thinking in terms of density
4. lead (Pb) is more dense than aluminum (Al), so $1g$ of Pb is much smaller ("takes up less space") than $1g$ of Al
5. we calculate density as $\rho = \frac{m}{V}$ where ρ is density, m is mass, and V is volume
6. ρ (density) can be measured in $\frac{kg}{L}$, or $\frac{kg}{m^3}$, or $\frac{g}{mL}$, or $\frac{g}{cm^3}$, or ...

6.1 Examples

Example 1 $1.00kg$ of Carbon occupies $0.4411L$. What is the density of Carbon in $\frac{kg}{L}$?

$$\boxed{\begin{aligned} \rho &= \frac{m}{V} \\ &= \frac{1kg}{0.4411L} \\ &= 2.26705962\frac{kg}{L} \\ &= 2.27\frac{kg}{L} \end{aligned}} \tag{7}$$

Example 2 $1.260kg$ of Copper occupies $0.140625L$. What is the density of Copper in $\frac{kg}{L}$?

$$\boxed{\begin{aligned} \rho &= \frac{m}{V} \\ &= \frac{1.260kg}{0.140625L} \\ &= 8.96\frac{kg}{L} \\ &= 8.960\frac{kg}{L} \end{aligned}} \tag{8}$$

Example 3 The density of Silicon is $1.00g$ per $0.429mL$. What is the mass of $3.24L$ of Silicon?

$$\boxed{\begin{aligned} \rho &= \frac{m}{V} \\ (\rho)(V) &= (\frac{m}{V})(V) \\ (\rho)(V) &= (\frac{m}{\cancel{V}})(\cancel{V}) \\ (\rho)(V) &= m \\ m &= (\rho)(V) \\ &= (\frac{1.00g}{0.429mL})(3.24L) \\ &= (\frac{1.00g}{0.429mL})(\frac{3.24L}{1})(\frac{1000mL}{1L}) \\ &= (\frac{1.00g}{0.429\cancel{mL}})(\frac{3.24\cancel{L}}{1})(\frac{1000\cancel{mL}}{1\cancel{L}}) \\ &= 7552.447552g \\ &= 7550g \end{aligned}} \tag{9}$$

7 Homework

Review Problems: p. 35 # 1–10
Practice Problems: p. 36 # 1–10 (due 2025-09-05)

References

[Wile, 2003] Wile, J. L. (2003). *Exploring Creation with Chemistry.* Apologia Educational Ministries, Inc., 2 edition.