Sections 2.5 (Atoms-First) and 8.5 (Chemistry-First) A Summary of the Unit Analysis Process

An Introduction to Chemistry
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Steps for Calculations Using Unit Analysis

- **Step 1** State your question in an expression that sets the unknown unit(s) equal to one or more of the values given.
  - To the left of the equals sign, show the unit(s) you want in your answer.

Steps for Calculations Using Unit Analysis

- **Step 1** (cont.)
  - To the right of the equals sign, start with an expression composed of the given unit(s) that parallels in kind and placement the units you want in your answer.
    - If you want a single unit in your answer, start with a value that has a single unit.
    - If you want a ratio of two units in your answer, start with a value that has a ratio of two units, or start with a ratio of two values, each of which has one unit.
    - Put each type of unit in the position you want it to have in the answer.

Steps for Calculations Using Unit Analysis

- **Step 2** Multiply the expression to the right of the equals sign by conversion factors that cancel unwanted units and generate the desired units.
  - If you are not certain which conversion factor to use, ask yourself, "What is the fundamental conversion the problem requires, and what conversion factor do I need to make that type of conversion?" Figures 2.3 (atoms-first) or 8.3 (chemistry-first) provide a guide to useful conversion factors.

Conversion Types

$$\text{Metric unit} \xrightleftharpoons[\text{(same type of measurement)}]{\text{Conversion factors from prefixes on Table 1.2}} \text{Another metric unit}$$

$$\text{English length unit} \xrightleftharpoons{\frac{2.54\text{ cm}}{1\text{ in.}} \text{ or conversion factors in Table 2.1 \& 8.1}} \text{Metric length unit}$$

$$\text{English mass unit} \xrightleftharpoons{\frac{453.6\text{ g}}{1\text{ lb}} \text{ or conversion factors in Table 2.1 \& 8.1}} \text{Metric mass unit}$$

$$\text{English volume unit} \xrightleftharpoons{\frac{3.785\text{ L}}{1\text{ gal}} \text{ or conversion factors in Table 2.1 \& 8.1}} \text{Metric volume unit}$$

$$\text{English unit} \xrightleftharpoons[\text{(same type of measurement)}]{\text{Conversion factors in Table A.5 Appendix A}} \text{Another English unit}$$

$$\text{Mass} \xrightleftharpoons{\text{Density as a conversion factor}} \text{Volume}$$

$$\text{Mass of a part} \xrightleftharpoons{\text{For X\% by mass } \frac{\text{X (any mass unit) part}}{\text{100 (same mass unit) whole}}} \text{Mass of a whole}$$

$$\text{Volume of a part} \xrightleftharpoons{\text{For X\% by volume } \frac{\text{X (any volume unit) part}}{\text{100 (same volume unit) whole}}} \text{Volume of a whole}$$

Steps for Calculations Using Unit Analysis

- **Step 3** Do a quick check to be sure you used correct conversion factors and that your units cancel to yield the desired unit(s).
- **Step 4** Do the calculation, rounding your answer to the correct number of significant figures and combining it with the correct unit.

Example 2.12 and 8.12: Convert 4567.36 micrograms to kilograms.

- First, we set the unit that we want equation to the value given.

$$? \text{ kg} = 4567.36 \text{ µg}$$

- Next, we set up the skeleton of the next conversion factor.

$$? \text{ kg} = 4567.36 \cancel{\text{µg}} \left(\frac{\quad}{\cancel{\text{µg}}} \right)$$

- When converting from one SI unit to another, it is most reliable to convert from the unit you have to the base unit and then from the base unit to the unit you want.

$$? \text{ kg} = 4567.36 \cancel{\text{µg}} \left(\frac{\cancel{\text{g}}}{\cancel{\text{µg}}} \right) \left(\frac{\text{kg}}{\cancel{\text{g}}} \right)$$

Example 2.12 and 8.12: Convert 4567.36 micrograms to kilograms.

$$? \text{ kg} = 4567.36 \cancel{\mu g}\left(\frac{1 \text{ g}}{10^6 \cancel{\mu g}}\right)$$

$$? \text{ kg} = 4567.36 \cancel{\mu g}\left(\frac{1 \cancel{g}}{10^6 \cancel{\mu g}}\right)\left(\frac{\quad}{\cancel{g}}\right)$$

$$? \text{ kg} = 4567.36 \cancel{\mu g}\left(\frac{1 \cancel{g}}{10^6 \cancel{\mu g}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{g}}\right)$$

$$? \text{ kg} = 4567.36 \cancel{\mu g}\left(\frac{1 \cancel{g}}{10^6 \cancel{\mu g}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{g}}\right) = \mathbf{4.56736 \times 10^{-6} \text{ kg}}$$

Example 2.12 and 8.12: Convert 4567.36 micrograms to kilograms.

Converts given metric unit to metric base unit

Desired unit

$$? \text{ kg} = 4567.36 \cancel{\mu\text{g}} \left(\frac{1 \cancel{\text{g}}}{10^6 \cancel{\mu\text{g}}} \right) \left(\frac{1 \text{ kg}}{10^3 \cancel{\text{g}}} \right) = \mathbf{4.56736 \times 10^{-6} \text{ kg}}$$

Given value

Converts metric base unit to desired metric unit

Example 2.13 and 8.13: Convert 475 miles to kilometers.

$$? \text{ km} = 475 \text{ mi}$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{}{\cancel{\text{mi}}} \right)$$

- We are converting from English length to SI length, and 2.54 cm per inch is a good conversion factor to use for this because it is exact.
- Our problem becomes a three-step problem.

  mi → in. → cm → km

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \text{ ft}}{1 \cancel{\text{mi}}} \right)$$

Example 2.13 and 8.13: Convert 475 miles to kilometers.

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{\quad}{\cancel{\text{ft}}}\right)$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \text{ in.}}{1 \cancel{\text{ft}}}\right)$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{\quad}{\cancel{\text{in.}}}\right)$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{2.54 \text{ cm}}{1 \cancel{\text{in.}}}\right)$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in.}}}\right)\left(\frac{\quad}{\cancel{\text{cm}}}\right)$$

Example 2.13 and 8.13: Convert 475 miles to kilometers.

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in.}}}\right)\left(\frac{1 \text{ m}}{10^2 \cancel{\text{cm}}}\right)$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in.}}}\right)\left(\frac{1 \cancel{\text{m}}}{10^2 \cancel{\text{cm}}}\right)\left(\frac{\quad}{\cancel{\text{m}}}\right)$$

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in.}}}\right)\left(\frac{1 \cancel{\text{m}}}{10^2 \cancel{\text{cm}}}\right)\left(\frac{1 \text{ km}}{10^3 \cancel{\text{m}}}\right)$$

Example 2.13 and 8.13: Convert 475 miles to kilometers.

- When you do the calculation, the calculator shows 764.4384.

English-metric conversion factor

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{5280 \cancel{\text{ft}}}{1 \cancel{\text{mi}}}\right)\left(\frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}}\right)\left(\frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in.}}}\right)\left(\frac{1 \cancel{\text{m}}}{10^2 \cancel{\text{cm}}}\right)\left(\frac{1 \text{ km}}{10^3 \cancel{\text{m}}}\right) = \mathbf{764 \text{ km}}$$

English-English unit conversions   metric-metric unit conversions

- Memorizing other English-metric conversion factors will save you time and effort. For example, if you know that 1.609 km = 1 mi, the problem becomes much easier.

$$? \text{ km} = 475 \cancel{\text{mi}} \left(\frac{1.609 \text{ km}}{1 \cancel{\text{mi}}}\right) = \mathbf{764 \text{ km}}$$

Example 2.14 and 8.14: What is the volume in liters of 64.567 pounds of ethanol at 20 °C?

$$? \text{ L} = 64.567 \text{ lb}$$

- Pound is a mass unit, and we want volume in liters. Density provides a conversion factor that converts between mass and volume. You can find the density of ethanol on a table such as Table 2.2 (8.2). It is 0.7893 g/mL at 20 °C.
- Our problem becomes a three-step problem.

  lb → g → mL → L

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{\phantom{453.6 \text{ g}}}{\cancel{\text{lb}}} \right)$$

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{453.6 \text{ g}}{1 \cancel{\text{lb}}} \right)$$

Example 2.14 and 8.14: What is the volume in liters of 64.567 pounds of ethanol at 20 °C?

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{453.6 \cancel{\text{g}}}{1 \cancel{\text{lb}}}\right)\left(\frac{\phantom{1 \text{ mL}}}{\cancel{\text{g}}}\right)$$

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{453.6 \cancel{\text{g}}}{1 \cancel{\text{lb}}}\right)\left(\frac{1 \text{ mL}}{0.7893 \cancel{\text{g}}}\right)$$

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{453.6 \cancel{\text{g}}}{1 \cancel{\text{lb}}}\right)\left(\frac{1 \cancel{\text{mL}}}{0.7893 \cancel{\text{g}}}\right)\left(\frac{\phantom{1 \text{ L}}}{\cancel{\text{mL}}}\right)$$

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{453.6 \cancel{\text{g}}}{1 \cancel{\text{lb}}}\right)\left(\frac{1 \cancel{\text{mL}}}{0.7893 \cancel{\text{g}}}\right)\left(\frac{1 \text{ L}}{10^3 \cancel{\text{mL}}}\right)$$

$$? \text{ L} = 64.567 \cancel{\text{lb}} \left(\frac{453.6 \cancel{\text{g}}}{1 \cancel{\text{lb}}}\right)\left(\frac{1 \cancel{\text{mL}}}{0.7893 \cancel{\text{g}}}\right)\left(\frac{1 \text{ L}}{10^3 \cancel{\text{mL}}}\right) = \mathbf{37.11 \text{ L}}$$

Conversion Factors from "Something per Something" Statements

- Anything that can be read as "something per something" can be used as a unit analysis conversion factor. For example, if a car is moving at 55 miles *per* hour, we could use the following conversion factor to convert from distance traveled in miles to time in hours or time in hours to distance traveled in miles.

$$\left(\frac{55\ \text{mi}}{1\ \text{hr}}\right)$$

- If you are building a fence, and plan to use four nails *per* board, the following conversion factor allows you to calculate the number of nails necessary to nail up 94 fence boards.

$$\left(\frac{4\ \text{nails}}{1\ \text{fence board}}\right)$$

Example 2.15 and 8.15: The label on a can of cat food tells you there are 0.94 lb of cat food per can with 0.15% calcium. If there are three servings per can, how many grams of calcium are in each serving?

- It is a good strategy write down the values you are given in the problem, and if things you are given can be written as ratios, it's a good idea idea them as conversion factors.
- Note that two phrases in this question can be read as "something per something" so they can be used as a unit analysis conversion factors. The phrase "three servings per can" leads to the first conversion factor below, and "0.94 lb of cat food per can" leads to the second.
- Assuming that 0.15% is a mass percent, we can build the third conversion factor below.

$$\left(\frac{3\ \text{serv.}}{1\ \text{can}}\right) \qquad \left(\frac{0.94\ \text{lb food}}{1\ \text{can}}\right) \qquad \left(\frac{0.15\ \text{lb Ca}}{100\ \text{lb food}}\right)$$

Example 2.15 and 8.15: The label on a can of cat food tells you there are 0.94 lb of cat food per can with 0.15% calcium. If there are three servings per can, how many grams of calcium are in each serving?

$$? \text{ g Ca} = \text{One serv.}$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{\quad}{\cancel{\text{serv.}}} \right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \text{ can}}{3 \cancel{\text{ serv.}}} \right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}} \right) \left(\frac{\quad}{\cancel{\text{can}}} \right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}} \right) \left(\frac{0.94 \text{ lb food}}{1 \cancel{\text{ can}}} \right)$$

Example 2.15 and 8.15: The label on a can of cat food tells you there are 0.94 lb of cat food per can with 0.15% calcium. If there are three servings per can, how many grams of calcium are in each serving?

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}}\right)\left(\frac{0.94 \cancel{\text{ lb food}}}{1 \cancel{\text{ can}}}\right)\left(\frac{\quad}{\cancel{\text{lb food}}}\right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}}\right)\left(\frac{0.94 \cancel{\text{ lb food}}}{1 \cancel{\text{ can}}}\right)\left(\frac{0.15 \text{ lb Ca}}{100 \cancel{\text{ lb food}}}\right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}}\right)\left(\frac{0.94 \cancel{\text{ lb food}}}{1 \cancel{\text{ can}}}\right)\left(\frac{0.15 \cancel{\text{ lb}} \text{ Ca}}{100 \cancel{\text{ lb food}}}\right)\left(\frac{\quad}{\cancel{\text{lb}}}\right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}}\right)\left(\frac{0.94 \cancel{\text{ lb food}}}{1 \cancel{\text{ can}}}\right)\left(\frac{0.15 \cancel{\text{ lb}} \text{ Ca}}{100 \cancel{\text{ lb food}}}\right)\left(\frac{453.6 \text{ g}}{1 \cancel{\text{ lb}}}\right)$$

$$? \text{ g Ca} = \text{One } \cancel{\text{serv.}} \left(\frac{1 \cancel{\text{ can}}}{3 \cancel{\text{ serv.}}}\right)\left(\frac{0.94 \cancel{\text{ lb food}}}{1 \cancel{\text{ can}}}\right)\left(\frac{0.15 \cancel{\text{ lb}} \text{ Ca}}{100 \cancel{\text{ lb food}}}\right)\left(\frac{453.6 \text{ g}}{1 \cancel{\text{ lb}}}\right) = \mathbf{0.21 \text{ g Ca}}$$

Example 2.16 and 8.16: When 2.3942 kg of the sugar glucose are burned (combusted), 37,230 kJ of heat are evolved. What is the heat of combustion of glucose in J/g?

- When the answer you want is a ratio of two units, make it clear which unit you want on the top and which unit you want on the bottom

$$\frac{?\ \text{J}}{\text{g glucose}} =$$

- If you want two units, start your unit analysis setup with a ratio of two units. Put the correct type of unit in the correct position in the ratio. For this problem, we put the heat unit on the top and the mass unit on the bottom. (Heat evolved is described with a negative sign.)

$$\frac{?\ \text{J}}{\text{g glucose}} = \frac{-37{,}230\ \text{kJ}}{2.3942\ \text{kg glucose}}$$

Example 2.16 and 8.16: When 2.3942 kg of the sugar glucose are burned (combusted), 37,230 kJ of heat are evolved. What is the heat of combustion of glucose in J/g?

$$\frac{?\ \text{J}}{\text{g glucose}} = \frac{-37{,}230\ \cancel{\text{kJ}}}{2.3942\ \text{kg glucose}}\left(\frac{\quad}{\cancel{\text{kJ}}}\right)$$

$$\frac{?\ \text{J}}{\text{g glucose}} = \frac{-37{,}230\ \cancel{\text{kJ}}}{2.3942\ \text{kg glucose}}\left(\frac{10^3\ \text{J}}{1\ \cancel{\text{kJ}}}\right)$$

$$\frac{?\ \text{J}}{\text{g glucose}} = \frac{-37{,}230\ \cancel{\text{kJ}}}{2.3942\ \cancel{\text{kg}}\ \text{glucose}}\left(\frac{10^3\ \text{J}}{1\ \cancel{\text{kJ}}}\right)\left(\frac{\cancel{\text{kg}}}{\quad}\right)$$

$$\frac{?\ \text{J}}{\text{g glucose}} = \frac{-37{,}230\ \cancel{\text{kJ}}}{2.3942\ \cancel{\text{kg}}\ \text{glucose}}\left(\frac{10^3\ \text{J}}{1\ \cancel{\text{kJ}}}\right)\left(\frac{1\ \cancel{\text{kg}}}{10^3\ \text{g}}\right)$$

$$\frac{?\ \text{J}}{\text{g glucose}} = \frac{-37{,}230\ \cancel{\text{kJ}}}{2.3942\ \cancel{\text{kg}}\ \text{glucose}}\left(\frac{10^3\ \text{J}}{1\ \cancel{\text{kJ}}}\right)\left(\frac{1\ \cancel{\text{kg}}}{10^3\ \text{g}}\right) = \mathbf{-15{,}550\ J/g}$$

Practice

- You can get some unit analysis practice by working Exercise 2.10 (8.10) and end-of-chapter problems 74-102.