APPENDIX B – THE FACTOR LABEL METHOD

Introduction

Stoichiometry is the science that deals with quantitative relationships between the elements in a compound (substance stoichiometry) or between the compounds and/or elements involved in a chemical reaction (reaction stoichiometry). A typical stoichiometry problem involves the conversion of a given quantity of one substance into an equivalent amount of another substance, and the factor label method is a common way to solve these problems. This section introduces the method.

B.1. The Factor Label Method

Introduction

The ***factor label method*** uses factors to convert one quantity into another. The labels (units) on the quantities and factors are used to determine how the factors are used.

Objectives

- Use the factor-label method in calculations.
- Distinguish between a quantity and a factor.
- Recognize a factor.

B.1-1. Factors and Quantities

A quantity has only one unit, while a factor contains two units.

Quantity

Most numerical problems in chemistry involve the conversion of one amount into another equivalent amount. The following are some examples:

- mass ↔ volume
- mass of substance A ↔ mass of substance B
- mass ↔ number of atoms or molecules
- volume of solution ↔ number of molecules or ions

The factor-label method is a common method to solve these types of problems. In the factor label method, we usually begin with a quantity and use factors to change its units or to change it into an equivalent amount of a different quantity, so it is important to understand the difference between a quantity and a factor. A ***quantity*** is simply an amount and is characterized by a single unit. The following are quantities.

- 10 g of salt
- 20 mL of water
- 30 °C
- 3.5 mol HCl
- 3 atm of HF

Factor

A ***factor*** represents the ratio of two equivalent quantities and is characterized by two units. For example, the equality 60 s = 1 min is expressed by the factor 60 s/1 min, which is used to convert seconds ↔ minutes. The following are also factors.

- 44 g/mol
- 1.0 g/mL
- 760 torr/atm

- 2.5 mol/L
- 2.54 cm/in
- 454 g/lb
- 20% C by mass, which can be expressed as 20 g C/100 g sample

Factors can also be given by identifying the two related quantities as separate amounts:

- 46 g of Na are combined with 16 g of O. Since the masses are related to one another, we can use them as a conversion factor: 46 g Na/16 g O.
- 3 mol H_2 are required to produce 2 mol NH_3 can be expressed as 3 mol H_2/2 mol NH_3.

B.1-2. Quantity or Factor Exercises

<u>EXERCISE B.1</u>:

Indicate whether each statement is giving a quantity or a factor.

The length of the string is 6.5 cm.
- quantity
- factor

The concentration of salt in the ocean is about 0.5 mol/L.
- quantity
- factor

A solution contains 2 g of Pb^{2+} for every 5 g of Ca^{2+}.
- quantity
- factor

A brass is 67% copper by mass.
- quantity
- factor

The density of the solution is 1.2 g/mL.
- quantity
- factor

A beaker contains 2 g of Pb, and another contains 5 g of Ca.
- quantity
- factor

Aluminum oxide contains 3 aluminum atoms for every 2 oxygen atoms.
- quantity
- factor

A solution is made by dissolving 12 g of salt in 145 mL of water.
- quantity
- factor

B.1-3. Single Factor Conversions

Factors are used to convert the units of a given quantity into those of an equivalent quantity with the factor-label method.

In the factor-label method, a quantity is multiplied by a conversion factor to convert it into an equivalent quantity with different units. The way that the factor appears in the multiplication is dictated by the labels (units) of the quantity and the factor. **Conversion factors are always written so that the units of their denominators are the same as those of the given quantity, and the units of their numerators are the same as those of the desired quantity.**

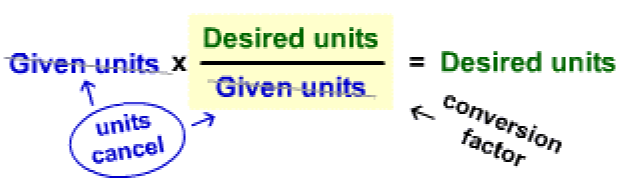

Figure B.1: The Conversion Factor Method One quantity can be converted to another by canceling the units.

For example, to determine the number of seconds in 3.5 minutes, you would multiply the given quantity (3.5 min) by the factor (60 s/1 min) to cancel the minutes and produce seconds.

$$3.5\ \cancel{\text{min}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} = 210\ \text{s}$$

However, to determine the number of minutes in 231 seconds, you would multiple the given quantity (231 s) by the factor (1 min/60 s) to cancel seconds and produce minutes.

$$231 \cancel{s} \times \frac{1 \text{ min}}{60 \cancel{s}} = 3.85 \text{ min}$$

When using the factor label method, it is good practice to include the substance in the label.

In order to maximize the utility of the factor label method, it is important to include the substance in the label. For example, 'g' and 'mL' are acceptable labels, but 'g Na' and 'mL solution' are much better. Consider that a solution of sodium chloride that has a concentration of 0.5 g/1 mL has a density of 1 g/1 mL. Written in this way the concentration and density are indistinguishable, which makes them far less useful when doing a problem. However, if we write that the concentration is 0.5 g NaCl/1 mL solution and the density is 1 g solution/1 mL solution, the two factors are readily distinguished and much more useful in doing a problem. Most of the problems we will deal with in this course involve more than one substance, so including the substance in the factors is very important.

B.1-4. Single Factor Exercises

EXERCISE B.2:

Use the factor-label method to solve the following. Enter each quantity and the abbreviation for its units as given in the problem separated by a single space. Do not include the substance.

A bag of marbles contains 3 red marbles for every 2 blue marbles. How many red marbles are in a bag that contains 18 blue marbles? Use RM and BM for red marbles and blue marbles, respectively.

$$\_\_\_\_ \times \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_$$

The density of a liquid is 0.740 g/mL. What is the volume of 86.0 g of the liquid? Use g and mL units.

$$\_\_\_\_ \times \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_$$

The density of a liquid is 0.740 g/mL. What is the mass of 127 mL of the liquid?

$$\_\_\_\_ \times \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_$$

What volume of solution would be required to obtain 18 g of NaCl if the solution is prepared by dissolving 35 g of NaCl in enough water to make 450 mL of solution?

$$\_\_\_\_ \times \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_$$

A solution is prepared by dissolving 12 g of sugar in enough water to make 285 mL of solution. How many g sugar are in 375 mL of solution?

$$\_\_\_\_ \times \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_$$

B.1-5. Multiple Factor Conversions

Conversion factors can be strung together, but the denominator of each should be the same as the numerator of the preceding factor.

Conversions cannot always be done conveniently with a single factor. In these instances, more than one factor may be required. However, the product of a quantity and a factor is simply another quantity, which can then be multiplied by another factor to produce yet another quantity. Each successive quantity can be multiplied by yet another factor to produce new quantities until the desired quantity is obtained. Once again, we use the labels of the factors to determine the order and manner in which the factors are used. The guiding rule is that **the units of each denominator *must* be the same as the label of the preceding numerator**. If this method is followed, the unit of the produced quantity will always be the same as the numerator of the final factor because all other units will cancel. The following example determines the number of years in 5.6×10^6 seconds.

$$5.6 \times 10^6\ \cancel{\text{s}} \times \frac{1\ \cancel{\text{min}}}{60\ \cancel{\text{s}}} \times \frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}} \times \frac{1\ \cancel{\text{d}}}{24\ \cancel{\text{h}}} \times \frac{1\ \text{yr}}{365\ \cancel{\text{d}}} = 0.18\ \text{yr}$$

The first multiplication converts seconds to minutes, the next converts the minutes to hours, the next converts the hours to days, and the final conversion takes days into years, the desired units. Note that all of the units cancel except the desired units.

B.1-6. Multiple Factor Exercises

EXERCISE B.3:

Enter each quantity and the abbreviation for its units as given in the problem separated by a single space. Do not include the substance.

What is the total cost of the gasoline required for a 675 mile trip, if gasoline is 4.06 USD/gal and the car gets 25.3 mi/gal? Use mi, gal, and USD. USD = US dollar.

$$\_\_\_\_ \times \frac{\_\_\_\_}{\_\_\_\_} \times \frac{\_\_\_\_}{\_\_\_\_} = \_\_\_\_$$