14.6: Molarity

Learning Objectives

- Use molarity as a conversion factor in calculations.

Of all the quantitative measures of solution concentration, molarity is the one used most frequently by chemists. **Molarity** is defined as the number of moles of solute per liter of solution.

$$\text{molarity} = \frac{\text{moles of solute}}{\text{Liters of solution}} \tag{14.6.1}$$

This means that molarity may be expressed in units of mol/L, though the abbreviation M (must be capitalized) is used more often to abbreviate molarity. Equation 14.6.1 may be written more simply as:

$$\text{M} = \frac{\text{mol}}{\text{L}} \tag{14.6.2}$$

Perhaps you have used a solution of 0.50 M HCl in lab. This concentration is read as "0.50 molar HCl" and means that there is 0.50 mol HCl dissolved for every one liter of solution. This concentration may also be written as 0.50 mol/L HCl. It is important to remember that “mol” in this expression refers to moles of *solute* and that “L” refers to liters of *solution*. In some instances, the molarity of a solution is instead called its **molar concentration**.

Units of molarity are useful for discussing chemical reactions in which a solute is a product or reactant. Molar masses may then be used as conversion factors to convert amounts in moles to amounts in grams. Sometimes chemists use square brackets to indicate a reference to the molarity of a substance. For example, the expression $[\text{Ag}^+]$ refers to the molarity of the silver ion in solution.

Kool-Aid

It turns out that making a solution of known molarity is similar to the preparation of Kool-Aid (see Figure 14.6.1 below) in that the total amount of *solution* is specified rather than the amount of *solvent*. Note that the front side of the Kool-Aid package reads, "Makes 2 Quarts," while the back side instructs one to add all of the other ingredients first before adding water to make a total of two quarts of Kool-Aid. If instead, two quarts of water had been added to the other ingredients, more than two quarts of Kool-Aid would be prepared, and the drink would taste watered down. The procedure for making Kool-Aid and its resemblance to preparing solutions of known molarity lead many students to affectionately call it the "Kool-Aid Rule".

Figure 14.6.1: The front and back sides of a package of unsweetened Kool-Aid.

Important Notes About Molarity

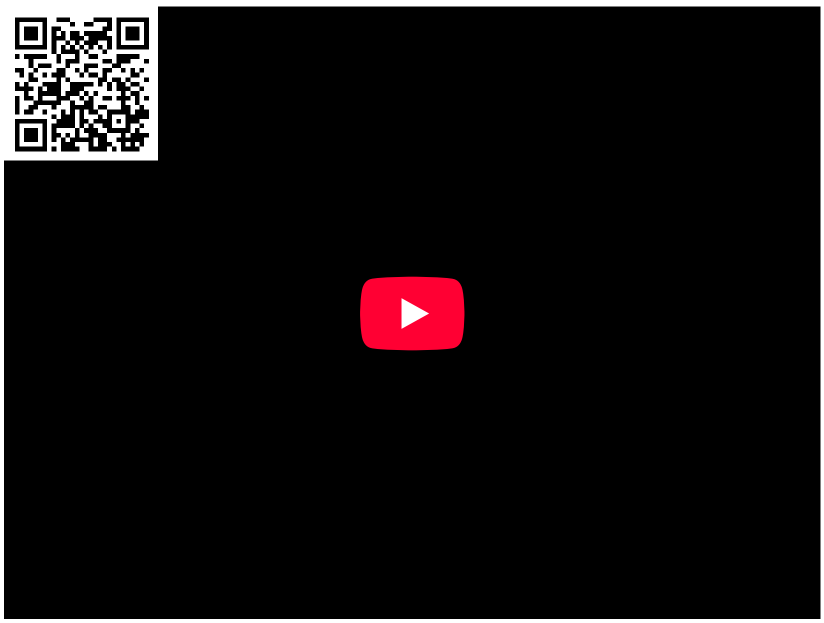
- The capital letter M is used for *molarity*, not a lower case m which is for a different concentration unit called *molality*.
- Molarity is calculated from the volume of *solution*, **not** the volume of *solvent*! The solute contributes to the total volume of the solution.
- The *molarity* of a solution is the same as its *molar concentration*.
- Square brackets are often used to represent molar concentration. Example: $[NH_3]$ = 0.50 M.

Before getting into more involved examples, let's look at the preparation of 1.00 L of a 1.00 M $NaHCO_3$ solution. A 1.00 M $NaHCO_3$ solution contains 1 mol $NaHCO_3$, or 84.0 g $NaHCO_3$ for every 1 L of solution (if necessary, review molar mass calculations). To make 1.00 L of this solution, a device that measures volume precisely will be needed. One option is to use a large graduated cylinder capable of measuring 1000 mL. However, there is a specific piece of equipment designed for this purpose that measures one volume very precisely called a *volumetric flask*. Volumetric flasks come in various sizes, so a 1000-mL volumetric flask would be selected to prepare 1.00 L of solution.

Figure 14.6.2: An assortment of volumetric flasks. (Nuno Nogueira via Wikimedia Commons)

Next, 84.0 g $NaHCO_3$ would be weighed on a scale and added to the volumetric flask. Since solid residue could remain on the measuring device, it should be rinsed with water and added to the volumetric flask. Water is then added to the flask until it is ½ to ¾ full. The contents of the flask are then mixed thoroughly until all of the solid dissolves. Recall that volumes are not always additive due to particle size and intermolecular forces, so make sure that the solute completely dissolves before adding water to the 1000-mL etched mark on the neck of the flask. Finally, water would be added to the 1000-mL mark on the neck and the solution would be thoroughly mixed.

Video 14.6.1 below shows how to make 1.00 L of a 1.00 M NaCl solution. Can you tell an important step that was skipped near the end of the video?



Video 14.6.1: Making a 1.00 M NaCl solution. One important step was skipped at the very end. What is it? (CAYERCHEM via YouTube)

You would be correct if you said they forgot to mix the solution thoroughly after the last portion of water was added to the flask. It is important that solutions are mixed thoroughly to obtain a uniform concentration of solute throughout the solution.

✅ Example 14.6.1

What is the molarity of 2.50 L of solution that contains 62.6 g $Mg(NO_3)_2$?

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 62.6 g $Mg(NO_3)_2$; 2.50 L solution Find: Molarity = ? M
List known relationship(s).	1 mol $Mg(NO_3)_2$ = 148.33 g $Mg(NO_3)_2$ $M = \frac{\text{mol}}{\text{L}}$

Steps for Problem Solving	
Prepare a concept map and use the proper conversion factor(s).	Convert mass $Mg(NO_3)_2$ to moles: $$\boxed{\text{g Mg(NO}_3)_2} \xrightarrow[148.33 \text{ g Mg(NO}_3)_2]{1 \text{ mol Mg(NO}_3)_2} \boxed{\text{mol Mg(NO}_3)}$$ Molarity is calculated by dividing moles by liters: $$\text{M} = \frac{\text{mol Mg(NO}_3)_2}{2.50 \text{ L}}$$
Calculate the answer.	Now substitute the known quantities and solve. $$62.6 \text{ g } \cancel{\text{Mg(NO}_3)_2} \times \frac{1 \text{ mol Mg(NO}_3)_2}{148.33 \text{ g } \cancel{\text{Mg(NO}_3)_2}} = 0.42\underline{2}0 \text{ g Mg(NO}_3)_2$$ $$\text{M} = \frac{0.42\underline{2}0 \text{ mol Mg(NO}_3)_2}{2.50 \text{ L}} = 0.169 \frac{\text{mol Mg(NO}_3)_2}{\text{L}} = \boxed{0.169 \text{ M Mg(NO}_3)_2}$$
Think about your result.	The molarity is 0.169 M, meaning that one liter of the solution would contain 0.169 mol $Mg(NO_3)_2$. Three significant figures are appropriate.

Exercise 14.6.1

A. Calculate the molar concentration of 0.500 L of solution in which 137 g NaCl are dissolved.
B. What is the molarity of a solution that contains 66.2 g $C_6H_{12}O_6$ dissolved in 235 mL of solution?

Answer A

4.69 M NaCl

Answer B

1.56 M $C_6H_{12}O_6$

Using Molarity as a Conversion Factor

Molarity may be used as a conversion factor to convert between moles of solute and liters of solution. As such, molarity can be useful in a variety of stoichiometry problems. For example, suppose we would like to know how many moles of NaCl are present in 108 mL of 0.887 M NaCl. Since molarity is defined as the moles of solute per liter of solution, this means that there are 0.887 mol NaCl for every 1 L of solution. However, the volume of solution is given in mL. Therefore, mL must first be converted to L or L must be converted to mL. As we recall, 1 L = 1000 mL, so 0.887 M NaCl may be expressed as a conversion factor in the form:

$$\frac{0.887 \text{ mol NaCl}}{1 \text{ L solution}} = \frac{0.887 \text{ mol NaCl}}{1000 \text{ mL solution}} \text{ or } \frac{1 \text{ L solution}}{0.887 \text{ mol NaCl}} = \frac{1000 \text{ mL solution}}{0.887 \text{ mol NaCl}}$$

The conversion that enables cancellation of units would then be used in the solution map that takes us from mL of solution to mol NaCl. With the solution map in place, the moles of NaCl are easily calculated.

$$\boxed{\text{mL solution}} \xrightarrow[1000 \text{ mL solution}]{0.887 \text{ mol NaCl}} \boxed{\text{mol NaCl}}$$

$$108 \text{ mL } \cancel{\text{solution}} \times \frac{0.887 \text{ mol NaCl}}{1000 \text{ mL } \cancel{\text{solution}}} = 0.0958 \text{ mol NaCl}$$

Had the equation approach been used instead, the same answer would be obtained. Since:

$$\text{M} = \frac{\text{mol}}{\text{L}}$$

this equation could be rearranged to solve for moles by multiplying each side by liters of solution. The result of this rearrangement is:

$$\text{mol} = \text{M} \times \text{L} \tag{14.6.3}$$

Note that using the equations requires that volumes be expressed in liters, so one would first convert 108 mL to 0.108 L, then plug the known quantities into the equation:

$$\text{mol} = 0.887 \text{ M NaCl} \times 0.108 \text{ L} = 0.887 \frac{\text{mol NaCl}}{\cancel{\text{L}}} \times 0.108 \cancel{\text{L}} = 0.0958 \text{ mol NaCl}$$

Whether using the conversion factor method or the equation method, it is still necessary to remember that M stands for mol/L, so the proper cancellation of units may be performed. However, once again, we can see that the same answer is obtained using either method.

What if we were looking for volume and wanted to know how many liters of 2.35 M $CuSO_4$ were needed to obtain 4.88 mol of $CuSO_4$? A molarity of 2.35 M $CuSO_4$ means that there are 2.35 mol $CuSO_4$ for every 1 L of solution. As such, 2.35 M $CuSO_4$ may be expressed as a conversion factor in the form:

$$\frac{2.35 \text{ mol CuSO}_4}{1 \text{ L solution}} \text{ or } \frac{1 \text{ L solution}}{2.35 \text{ mol CuSO}_4}$$

The conversion that enables cancellation of units would then be used in the solution map that takes us from mol $CuSO_4$ to L solution. With the solution map in place, the liters of solution are easily calculated.

$$\boxed{\text{mol CuSO}_4} \xrightarrow[2.35 \text{ mol CuSO}_4]{1 \text{ L solution}} \boxed{\text{L solution}}$$

$$4.88 \text{ mol } \cancel{\text{CuSO}_4} \times \frac{1 \text{ L solution}}{2.35 \text{ mol } \cancel{\text{CuSO}_4}} = 2.08 \text{ L solution}$$

✅ Example 14.6.2

A chemist needs to prepare 250.0 mL of a 0.150 M solution of potassium permanganate, $KMnO_4$.

A. What mass of $KMnO_4$ does she need to make the solution?
B. Describe how this solution would be prepared.

Solution

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 0.150 M $KMnO_4$; 250.0 mL solution Find: Mass $KMnO_4$ = ? g $KMnO_4$
List known relationship(s).	1 mol $KMnO_4$ = 158.04 g $KMnO_4$ 0.150 mol $KMnO_4$ for every 1 L (1000 mL) solution
Prepare a concept map and use the proper conversion factor(s).	$\boxed{\text{mL solution}} \xrightarrow[1000 \text{ mL solution}]{0.150 \text{ mol KMnO}_4} \boxed{\text{mol KMnO}_4} \xrightarrow[1 \text{ mol KMnO}_4]{158.04 \text{ g KMnO}_4}$
Calculate the answer.	Now substitute the known quantities and solve. $250.0 \text{ } \cancel{\text{mL solution}} \times \frac{0.150 \text{ } \cancel{\text{mol KMnO}_4}}{1000 \text{ } \cancel{\text{mL solution}}} \times \frac{158.04 \text{ g KMnO}_4}{1 \text{ } \cancel{\text{mol KMnO}_4}} = \boxed{5.93 \text{ g KMnO}_4}$
Think about your result.	When 5.93 g $KMnO_4$ are used to make 250.0 mL of solution, the molarity is 0.150 M.

B. To prepare the solution, weigh out 5.93 g $KMnO_4$ solid on a scale. Place the solid in a 250-mL volumetric flask. Add water to flask and mix to dissolve the solid. Add water until the bottom of the meniscus is on the line on the neck. Mix thoroughly.

✅ Example 14.6.3

What volume of a 0.200 M NaOH solution would contain 16.0 g NaOH?

Solution

Steps for Problem Solving	

Steps for Problem Solving	
Identify the "given" information and what the problem is asking you to "find."	Given: 0.200 M NaOH; 16.0 g NaOH Find: Volume of Solution = ? L
List known relationship(s).	1 mol NaOH = 40.00 g NaOH 0.200 mol NaOH for every 1 L solution
Prepare a concept map and use the proper conversion factor(s).	$\boxed{\text{g NaOH}} \xrightarrow[\text{40.00 g NaOH}]{\text{1 mol NaOH}} \boxed{\text{mol NaOH}} \xrightarrow[\text{0.200 mol NaOH}]{\text{1 L solution}} \boxed{\text{L sc}}$
Calculate the answer.	Now substitute the known quantities and solve. $16.0\ \cancel{\text{g NaOH}} \times \dfrac{1\ \cancel{\text{mol NaOH}}}{40.00\ \cancel{\text{g NaOH}}} \times \dfrac{1\text{ L solution}}{0.200\ \cancel{\text{mol NaOH}}} = \boxed{2.00\text{ L solution}}$
Think about your result.	When 16.0 g NaOH are used to make 2.00 L of solution, the molarity is 0.200 M.

Exercise 14.6.3

A. What mass of solute is present in 1.08 L of 0.0578 M H_2SO_4?
B. What is the volume of 0.0444 M CH_2O solution that contains 0.0773 mol CH_2O?
C. What volume of 1.50 M HCl solution, in mL, contains 10.0 g of hydrogen chloride?

Answer A

6.12 g H_2SO_4

Answer B

1.74 L

Answer C

183 mL or 0.183L