Learning Objectives

- Define molarity
- Differentiate between solute, solvent, and solution
- Calculate the molar concentration of a given solution
- Outline the steps to make a solution of a desired concentration from a solid solute
- Using molarity as a conversion factor, calculate the volume of solution or quantity (mass and moles) of a solute
- Calculate the concentration of ions in a soluble ionic compound
- Outline the steps to make a solution of a desired concentration from a more concentrated stock solution
- Manipulate the equation for solution dilution to calculate unknown variable based on known variables.

Introduction

Up to this point we have used stoichiometry to "count" atoms, molecules and ions by measuring mass of pure substances and using molar masses to calculate the number of chemical entities (moles). Many of the reactions we have studied involve solutions, where we are interested in a solute that is dissolved in a solvent, and we can not measure the mass of the solute independent of the solvent. We also need to realize that many chemical reactions require the reactants to be mobile, where they can bump into each other, and this can occur when they are dissolved in a solvent. So it is very important that we can count chemical entities when the entity of interest is a solute dissolved in a solvent.

Concentration of a Solution

There are two basic ways of reporting the concentration of a solute in a solvent, by reporting the mass of solute in a given volume of solution, or the number of moles of solute in a given volume of solution.

**Mass Concentration:** has typical units of g/L \[
\frac{\text{mass} \: \text{solute}}{\text{vol} \: \text{solution}} = \frac{m(\text{g})}{V(\text{L})} \]\n
**Mole Concentration (Molarity):** has units of mol/L or M \[
\frac{\text{moles} \: \text{solute}}{\text{vol} \: \text{solution}} = \frac{n(\text{moles})}{V(\text{L})} = M(\text{mol/L}) \]

So a 3.0M solution of sucrose has 3.0 mole of sucrose (solute) per liter of solution (sucrose + water), not per liter of solvent (water). Square brackets are used to represent the concentration of a solution. For example: \([\text{sucrose}] = 3.0 \: \text{M}\) means the concentration of the sucrose solution is 3.0 molar.

**Conventions**

- \(m\) = mass
- \(n\) = moles
- \(M\) = molarity
We most often represent the concentration of solutions in the lab in units of molarity. So, how do we calculate the molarity of a given solution? Let's do the following example.

Example \(\PageIndex{1}\)

A solution is prepared by dissolving 42.23 g of NH\(_4\)Cl in enough water to make 500.0 mL of solution. Calculate the molarity of the solution.

**Solution**

### Steps for Problem Solving

1. **Given:**
   - Mass: 42.23 g NH\(_4\)Cl
   - Volume solution: 500.0 mL
   - Final: Molarity = 1 M

2. **Lot other known quantities:**
   - Molar mass NH\(_4\)Cl = 53.50 g/mol

3. **Plan the problem:**
   - 1 mol NH\(_4\)Cl
   - 53.50 g NH\(_4\)Cl

4. **Carry out the calculation:**
   - \[
   \text{Molarity} = \frac{\text{Mass of solute}}{\text{Volume of solution}} = \frac{42.23 \text{ g NH}_4\text{Cl}}{500.0 \text{ mL}} = 0.08446 \text{ mol/L}
   \]

5. **Think about your result:**
   - The molarity is 0.08446 M, meaning that a liter of the solution would contain 0.08446 mol NH\(_4\)Cl, four significant figures are appropriate.

Exercise \(\PageIndex{1}\)

What is the molarity of a solution made when 66.2 g of C\(_6\)H\(_{12}\)O\(_6\) are dissolved to make 235 mL of solution?

**Answer**

1.57 \(\text{M C}_6\text{H}_12\text{O}_6\)

Original Source for Example 1 and Exercise 1 found at:

https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Introductory_Chemistry_(Tro)/13%3A_Solutions/13.06%3A_Specifying_Solution_Concentration%3A_Molarity

We saw how to calculate the molarity of a given solution. Now, let's see the steps required to make a desired volume of a solution with a specific molar concentration. The easiest method requires using a solid as a solute.

**Making a Solution with a Solid Solute.**

Step 1: Calculate Mass of solute needed for desired volume
Step 2: Quantitatively Transfer Mass to Volumetric Flask (the flask with the desired volume of solution)
Step 3: Dilute to volume with solvent, ensuring that all of the solid has dissolved.
Click the following video to watch a tutorial on how to make solutions with a specific molar concentration:

Using Molarity as Conversion Factor

In the example in the video, it was straightforward how much NaCl was needed to make a 1.0 M solution of NaCl. You need 1 mole (58.44 g of NaCl) per one liter of solution. However, in the laboratory, experiments call for various molar concentrations as well as various required volumes. We can use molarity as a conversion factor to make solutions that have a desired concentration. Let's see how to prepare a 500.0 mL copper(II) sulfate solution that has a 0.500 M concentration.

Making 500.0 mL of 0.500 M Copper(II)Sulfate

Step 1: Calculate Mass CuSO₄(s) needed given the molarity. 0.500 M means that there are 0.500 moles of CuSO₄ per 1 Liter of solution. So molarity is a conversion factor that allows you to convert between liters of solution and moles of solute (CuSO₄). Once you convert to moles of CuSO₄, you can easily convert to grams using your molar mass as a conversions factor. The other thing that we must note is that the volume of our solution is in milliters, so we must convert to liters first before using molarity as a conversion factor. So the steps become:
mL of solution → L of solution → moles of solute (CuSO\_4) → gram of solute (CuSO\_4)

Setting in up in dimensional analysis:

\[0.5000L \left( \frac{0.500\text{molCuSO}_4}{L} \right) \left( \frac{159.6\text{gCuSO}_4}{\text{mol}} \right) = 39.9\text{gCuSO}_4\]

Step 2: Weight 39.9g CuSO\_4(s) and quantitatively transfer to 500 mL graduated cylinder (which is calibrated to 500.0 mL), being sure all the salt is transferred.

Step 3: Fill half way and mix, then dilute to volume. Make sure all the solute is dissolved, and recheck that solution level is at bottom of meniscus.

Note: You CANNOT just add 500 mL of water (solvent) to the 39.9 g of CuSO\_4. The total volume of the solution is 500 mL including solute and solvent.

Exercise \(\PageIndex{2}\)

Using concentration as a conversion factor, perform the following calculation.

A) How many liters of 0.0444 M CH\_2\_O are needed to obtain 0.0773 mol of CH\_2\_O?

B) What mass of solute is present in 1.08 L of 0.0578 M H\_2\_SO\_4?

C) What volume of 1.50 M HCl solution contains 10.0 g of hydrogen chloride?

**Answer**

A) 1.74 L

B) 6.12 g

C) 183 mL or 0.183L

Original Source for Exercise 2 can be found here:

https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Map%3A_Introductory_Chemistry_(Tro)/13%3A_Solutions/13.06%3A_Specifying_Solution_Concentration%3A_Molarity
Ion Concentrations in Solution

As we have seen in Ch 3, when an ionic compound dissolves it breaks up into its ions.

\[(\text{NH}_4\text{)}_2\text{Cr}_2\text{O}_7(\text{aq}) \rightarrow 2\text{NH}_4^+(\text{aq}) + \text{Cr}_2\text{O}_7^{2-}(\text{aq})\]

Dissolving 252.07 grams of ammonium dichromate (fw = 252.07 g/mol) results in a solution that is 1M ammonium dichromate, but when an ionic salt dissolves, it breaks up into ions, and so what you really have is a solution that is 2 M ammonium ion (NH\text{4}^+) and 1 M in dichromate ion (Cr\text{2}O\text{7}^{2-})

Dissolution of 1 mol of an Ionic Compound. In this case, dissolving 1 mol of (NH\text{4})\text{2}Cr\text{2}O\text{7} produces a solution that contains 1 mol of Cr\text{2}O\text{7}^{2-} ions and 2 mol of NH\text{4}^+ ions. (Water molecules are omitted from a molecular view of the solution for clarity.)

Solution Concentrations in units of Molarity

Water is added to 2.16 g of the ionic compound ferrous chloride to make a solution with a total volume of 100.0 mL. Express the concentration of the salt solution, and that of its ions.

1. What is the salt concentration?
2. What are the ion concentrations?
3:36 min YouTube determining a salt's concentration, and that of its ions.

Exercise \(\PageIndex{3}\)

You have a 1.50 M solution of Na\(_2\)CO\(_3\). What is the concentration of:

A) sodium ions?

B) carbonate ions?

C) total ions?

**Answer**

A) \([\text{Na}^+]= 3.00\ \text{M}\)

B) \([\text{CO}_3^{2-}]= 1.50\ \text{M}\)

C) \([\text{Na}^+]+[\text{CO}_3^{2-}]= 4.50\ \text{M}\); or you can choose think for every 1 mole of Na\(_2\)CO\(_3\), there are 3 moles of ions (identify of the ions is irrelevant).

For more practice with feedback, click the following links:

http://chemcollective.org/activities/tutorials/stoich/solution_stoi
Making a Solution with a Stock Concentrated Solution (Dilution).

When preparing solution, we don't always start with a solid solute and dilute with solvent to create a solution of a certain molarity. Many stockroom reagents already come as concentrated solutions which can easily be diluted to a desired concentration by adding solvent. This is analogous to diluting a sweet drink by adding more water. You did not remove the sugar, but the drink becomes less sweet (less concentrated or more dilute) when you add more solvent. Adding a solvent does not change the moles of solute (n), so

\[ n_{\text{initial}} = n_{\text{final}} \]
\[ n_i = n_f \]
\[ M_iV_i = M_fV_f \]

Step 1: Calculate initial volume of stock

Step 2: Transfer to volumetric flask with a volumetric pipette

Step 3: Dilute to Volume

Making 500.0mL of 0.70M Hydrochloric Acid from 11.6 stock Hydrochloric Acid

Step 1: Calculate initial volume of 11.6 M hydrochloric acid needed.

\[ V_i = \frac{M_fV_f}{M_i} = \frac{0.70M \times 500mL}{11.6M} = 25mL \]

Step 2: Quantitatively transfer this volume to a 500 mL volumetric flask (this has 4 significant figures, that is, it is calibrated to 500.0 mL)
Step 3: Dilute with water to mark

2:30 min YouTube solving a dilution problem

VLab: Dilution Problems

In the virtual lab below contains the following concentrated stock solutions.

- 19 M NaOH
- 11.6 M HCl
- 17.8 M H₂SO₄
- 15.4 M HNO₃
- 15 M HClO₄
- 14.6 M H₃PO₄
- 14.8 M NH₃

Calculate the volume of each reagent that would be required to make 100 mL of a 1 M solution for each of the above. Then check your work by going to the stockroom of the virtual lab below, obtain a 100 mL volumetric flask and transfer the calculated volume of the stock reagent, and then dilute to volume. Note, in the virtual lab volumes are "additive", that is, 20 mL of 19M NaOH plus 80 mL will give 100 mL of a diluted solution. In the real world, volumes cannot be treated as additive, and adding 20 mL of a solution to 80 mL will typically result in less than 100 mLs of solution.

For practice with dilution with feedback, click the following links:

https://wwnorton.com/college/chemistry/chem4/chemtours.aspx  Click Ch 4, dilutions
Practice Problems

Dilution Worksheet
Dilution Worksheet Key