Molarity Concentration

Definition of Molarity

One of the most commonly used concentration units among chemists is the Molarity concentration term. Molarity is defined as the moles of solute divided by the volume of the solution in liter units. An alternative definition is the number of millimoles of solute divided by the volume of the solution in milliliters. The symbol that we use is the capital letter M. For example, if we have a 3 M HCl solution, then we have 3 moles of HCl in every liter of that solution. Alternatively, we can say that we have 3 millimoles of HCl in every milliliter of solution.

Section 1

A shortened term for this concentration term is the word "molar".

Application of the Molarity Term

Example Problem:

A sample of $NaNO_3$ weighing 8.5 grams is placed in a 500 ml volumetric flask and distilled water was added to the the mark on the neck of the flask. Calculate the Molarity of the resulting solution.

Solution

1. Convert the given grams of solute to moles of solute by dividing by the molecular weight of $NaNO_3$:

   1 mole $NaNO_3$ = Molecular mass of $NaNO_3$ expressed in grams = 23 + 14 + 3(16) = 85 grams

   8.5 grams $NaNO_3$ X 1 mole $NaNO_3$ / 85 grams $NaNO_3$ = 0.1 mole $NaNO_3$

2. Convert given ml of solution to liters by dividing by 1000:

   1 liter = 1000 ml

   500 ml X 1 liter / 1000 ml = .500 liters

3. Apply the definition for Molarity:

   Molarity = moles $NaNO_3$ / volume of the solution in liters

M = 0.1 mole / .500 liters = 0.200 Molar $NaNO_3$

Section 2

I. Basic molarity problems where the molarity is the unknown.

Example 1. What is the molarity of a 5.00 liter solution that was made with 10.0 moles of KBr ?

Solution: We can use the original formula. Note that in this particular example, where the number of moles of solute is given, the identity of the solute (KBr) has nothing to do with solving the problem.

$$\text{Molarity} = \frac{\text{\# of moles of solute}}{\text{Liters of solution}}$$

Given: # of moles of solute = 10.0 moles
Liters of solution = 5.00 liters

$$\text{Molarity} = \frac{\text{10.0 moles of KBr}}{\text{5.00 Liters of solution}} = 2.00\text{ M}$$

Answer = 2.00 M

Example 2. A 250 ml solution is made with 0.50 moles of NaCl. What is the Molarity of the solution?

Solution: In this case we are given ml, while the formula calls for L. We must change the ml to Liters as shown below:

$$250\ \cancel{\text{ml}} \times \frac{1\text{ liter}}{1000\ \cancel{\text{ml}}} = 0.25\text{ liters}$$

To avoid confusion, I will usually make the unit change right in the original question:

Example 2. A ~~250~~ **ml 0.25 L** solution is made with 0.50 moles of NaCl. What is the Molarity of the solution?

Now, solve the problem as you solved example 1.

$$\text{Molarity} = \frac{\text{\# of moles of solute}}{\text{Liters of solution}}$$

Given: Number of moles of solute = 0.50 moles of NaCl
Liters of solution = 0.25 L of solution

$$\text{Molarity} = \frac{\text{0.50 moles of NaCl}}{\text{0.25 L}} = \text{2.0 M solution}$$

Answer = 2.0 M solution of NaCl

II. Basic molarity problems where volume is the unknown.

This is similar to when we studied density, we have a formula with three possible unknowns. When the molarity of the solution and the number of moles of solute are given, but the volume is unknown, we must adjust our original formula to isolate the unknown variable. Observe:

$$\text{Molarity} = \frac{\text{\# of moles of solute}}{\text{Liters of solution}}$$

$$\text{Molarity} \times \text{Liters of solution} = \frac{\text{\# of moles of solute}}{\sout{\text{Liters of solution}}} \times \sout{\text{Liters of solution}}$$

$$\frac{\sout{\text{Molarity}} \times \text{Liters of solution}}{\sout{\text{Molarity}}} = \frac{\text{\# of moles of solute}}{\text{Molarity}}$$

$$\text{Liters of solution} = \frac{\text{\# of moles of solute}}{\text{Molarity}}$$

Example 1. What would be the volume of a 2.00 M solution made with 6.00 moles of LiF?

Solution:

$$\text{Liters of solution} = \frac{\text{\# of moles of solute}}{\text{Molarity}}$$

Given: # of moles of solute = 6.00 moles
Molarity = 2.00 M (moles/L)

$$\text{Liters of solution} = \frac{6.00\ \text{~~moles~~}}{2.00\ \text{~~moles~~/L}}$$

Answer = 3.00 L of solution

Now, you must also be prepared for the fact that the number of moles is not always given to you. Sometimes you will be given the mass of the solute and you will need to determine the number of moles by dividing the mass given by the Molar mass of the solute. In these cases, use the formula below.

$$\text{\# of moles} = \frac{\text{mass given}}{\text{Molar mass}}$$

Example 2. What is the volume of 3.0 M solution of NaCl made with 526g of solute?

Solution:

First find the molar mass of NaCl.

Na = 23.0 g x 1 ion per formula unit = 23.0 g
Cl = 35.5 g x 1 ion per formula unit = 35.5 g

58.5 g

Now find out how many moles of NaCl you have:

$$\text{\# of moles} = \frac{\text{mass of sample}}{\text{Molar mass}}$$

Given: mass of sample = 526 g
Molar mass = 58.5 g

$$\text{\# of moles of NaCl} = \frac{526\text{ g}}{58.5\text{ g}}$$

Answer: # of moles of NaCl = **8.99 moles**

Finally, go back to your molarity formula to solve the problem:

$$\text{Liters of solution} = \frac{\text{\# of moles of solute}}{\text{Molarity}}$$

Given: # of moles of solute = 8.99 moles
Molarity of the solution = 3.0 M (moles/L)

$$\text{\# of Liters of solution} = \frac{8.99\ \cancel{\text{moles}}}{3.0\ \cancel{\text{moles}}/\text{L}}$$

Final Answer = 3.0 L

III. Basic molarity problems where the number of moles is the unknown.

Of course, the total number of moles used in the creation of a solution might be unknown to you. However, given the molarity and the volume of the solution, you can determine the number of moles of solute. Observe:

$$\text{Molarity} = \frac{\text{\# of moles of solute}}{\text{Liters of solution}}$$

$$\text{Molarity x Liters of solution} = \frac{\text{\# of moles of solute}}{\cancel{\text{Liters of solution}}} \text{ x } \cancel{\text{Liters of solution}}$$

# of moles of solute = Molarity x Liters of solution.

Example 1. How many moles of $CaCl_2$ would be used in the making of 5.00×10^2 cm^3 of a 5.0M solution?

Notice that the volume is given in cm^3. Since there are 1000 cm^3 in 1 liter, 500 cm^3 must be equal to 0.500 liters. Make that change right in the problem.

Example 1. How many moles of $CaCl_2$ would be used in the making of ~~5.00×10^2 cm^3~~ 0.500 L of a 5.0M solution?

Now you are ready to solve.

Solution:

# of moles of solute = Molarity x Liters of solution.

Given: Molarity = 5.0 M (moles/L)
Volume = 0.500 L

# of moles of $CaCl_2$ = 5.0 ~~moles~~/L x 0.500 ~~moles~~

Answer = 2.5 moles of $CaCl_2$

Notice that the identity of the solute does not work into the math of the problem. However, if the wording was different, it would. Observe example # 2.

Example 2. How many grams of $CaCl_2$ would be used in the making of 5.00×10^2 cm^3 of a 5.0M solution?

In this case, what they are looking for is different. You could start to solve this problem the same way you did example 1, but the end would require you to change the number of moles of $CaCl_2$ to the mass of $CaCl_2$. You would use the formula below.

$$\# \text{ of moles} = \frac{\text{mass of sample}}{\text{Molar mass}}$$

$$\# \text{ of moles} \times \text{Molar mass} = \frac{\text{mass of sample}}{\cancel{\text{Molar mass}}} \times \cancel{\text{Molar mass}}$$

mass of sample = # moles of solute x Molar mass

Given: # of moles of solute = 2.5 moles (from our answer to example 1.)
Molar mass of solute ($CaCl_2$) = 111 g/mole (from the periodic table)

Mass of $CaCl_2$ = 2.5 ~~moles~~ x 111 g/~~mole~~

Answer: Mass of $CaCl_2$ = 280 g (when rounded correctly)

Section 3

Exercises (Answers at the back)

1.Sea water contains roughly 28.0 g of NaCl per liter. What is the molarity of sodium chloride in sea water?

2. What is the molarity of 245.0 g of H_2SO_4 dissolved in 1.00 L of solution?

3. What is the molarity of 5.30 g of Na_2CO_3 dissolved in 400.0 mL solution?

4. What is the molarity of 5.00 g of NaOH in 750.0 mL of solution?

5. How many moles of Na_2CO_3 are there in 10.0 L of 2.0 M soluton?

6. How many moles of Na_2CO_3 are in 10.0 mL of a 2.0 M solution?

7. How many moles of NaCl are contained in 100.0 mL of a 0.20 M solution?

8. What weight (in grams) of NaCl would be contained in problem 7?

9. What weight (in grams) of H_2SO_4 would be needed to make 750.0 mL of 2.00 M solution?

10. What volume (in mL) of 18.0 M H_2SO_4 is needed to contain 2.45 g H_2SO_4?

11. What volume (in mL) of 12.0 M HCl is needed to contain 3.00 moles of HCl?

12. How many grams of $Ca(OH)_2$ are needed to make 100.0 mL of 0.250 M solution?

13. What is the molarity of a solution made by dissolving 20.0 g of H_3PO_4 in 50.0 mL of solution?

14. What weight (in grams) of KCl is there in 2.50 liters of 0.50 M KCl solution?

15. What is the molarity of a solution containing 12.0 g of NaOH in 250.0 mL of solution?

16. Determine the molarity of these solutions:

a) 4.67 moles of Li_2SO_3 dissolved to make 2.04 liters of solution.
b) 0.629 moles of Al_2O_3 to make 1.500 liters of solution.
c) 4.783 grams of Na_2CO_3 to make 10.00 liters of solution.

d) 0.897 grams of $(NH_4)_2CO_3$ to make 250 mL of solution.
e) 0.0348 grams of $PbCl_2$ to form 45.0 mL of solution.

17. Determine the number of moles of solute to prepare these solutions:

a) 2.35 liters of a 2.00 M $Cu(NO_3)_2$ solution.
b) 16.00 mL of a 0.415-molar $Pb(NO_3)_2$ solution.
c) 3.00 L of a 0.500 M $MgCO_3$ solution.
d) 6.20 L of a 3.76-molar Na_2O solution.

18. Determine the grams of solute to prepare these solutions:

a) 0.289 liters of a 0.00300 M $Cu(NO_3)_2$ solution.
b) 16.00 milliliters of a 5.90-molar $Pb(NO_3)_2$ solution.
c) 508 mL of a 2.75-molar NaF solution.
d) 6.20 L of a 3.76-molar Na_2O solution.
e) 0.500 L of a 1.00 M KCl solution.
f) 4.35 L of a 3.50 M $CaCl_2$ solution.

19. Determine the final volume of these solutions:

a) 4.67 moles of Li_2SO_3 dissolved to make a 3.89 M solution.
b) 4.907 moles of Al_2O_3 to make a 0.500 M solution.
c) 0.783 grams of Na_2CO_3 to make a 0.348 M solution.
d) 8.97 grams of $(NH_4)_2CO_3$ to make a 0.250-molar solution.
e) 48.00 grams of $PbCl_2$ to form a 5.0-molar solution.

Answers

1. (x) (1.00 L) = 28.0 g / 58.45 g mol^{-1}; x = 0.479 M

2. (x) (1.00 L) = 245.0 g / 98.08 g mol^{-1}; x = 2.498 M

3. (x) (0.4000 L) = 5.30 g / 106.0 g mol^{-1}; x = 0.125 M

4. (x) (0.7500 L) = 5.00 g / 40.00 g mol^{-1}; x = 0.167 M

5. 2.0 M = x / 10.0 L

6. 2.0 M = x / 0.0100 L

7. 0.20 M = x / 0.1000 L

8. (0.20 mol L^{-1}) (0.100 L) = x / 58.45 g mol^{-1}

9. (2.00 mol L^{-1}) (0.7500 L) = x / 98.08 g mol^{-1}

10. (18.0 mol L^{-1}) (x) = 2.45 g / 98.08 g mol^{-1}

This calculates the volume in liters. Multiplying the answer by 1000 provides the required mL value.

11. 12.0 M = 3.00 mol / x

This calculates the volume in liters. Multiplying the answer by 1000 provides the required mL value.

12. (0.250 mol L^{-1}) (0.100 L) = x / 74.1 g mol^{-1}

13. (x) (0.050 L) = 20.0 g / 97.99 g mol^{-1}

14. (0.50 mol L^{-1}) (2.50 L) = x / 74.55 g mol^{-1}

15. (x) (0.2500 L) = 12.0 g / 40.00 g mol^{-1}

16. Determine the molarity of these solutions:

a) x = 4.67 mol / 2.04 L
b) x = 0.629 mol / 1.500 L
c) (x) (10.00 L) = 4.783 g / 106.0 g mol^{-1}

d) (x) (0.250 L) = 0.897 g / 96.09 g mol^{-1}
e) (x) (0.0450 L) = 0.0348 g / 278.1 g mol^{-1}

17. Determine the number of moles of solute to prepare these solutions:

a) x = (2.00 mol L^{-1}) (2.35 L)
b) x = (0.415 mol L^{-1}) (0.01600 L)
c) x = (0.500 mol L^{-1}) (3.00 L)
d) x = (3.76 mol L^{-1}) (6.20 L)

18. Determine the grams of solute to prepare these solutions:

a) (0.00300 mol L^{-1}) (0.289 L) = x / 187.56 g mol^{-1}
b) (5.90 mol L^{-1}) (0.01600 L) = x / 331.2 g mol^{-1}
c) (2.75 mol L^{-1}) (0.508 L) = x / 41.99 g mol^{-1}
d) (3.76 mol L^{-1}) (6.20 L) = x / 61.98 g mol^{-1}
e) (1.00 mol L^{-1}) (0.500 L) = x / 74.55 g mol^{-1}
f) (3.50 mol L^{-1}) (4.35 L) = x / 110.99 g mol^{-1}

19. Determine the final volume of these solutions:

a) x = 4.67 mol / 3.89 mol L^{-1}
b) x = 4.907 mol / 0.500 mol L^{-1}
c) (0.348 mol L^{-1}) (x) = 0.783 g / 105.99 g mol^{-1}
d) (0.250 mol L^{-1}) (x) = 8.97 g / 96.01 g mol^{-1}
e) (5.00 mol L^{-1}) (x) = 48.0 g / 278.1 g mol^{-1}