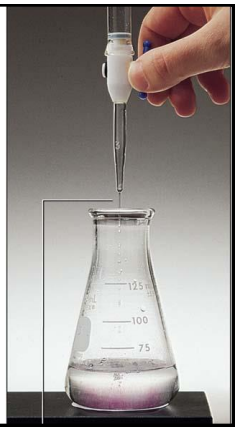
Solution Concentration & Stoichiometry

Chapter 4.5-6



Molarity (M)

Molarity (M) is

- a concentration term for solutions
- the moles of solute in 1 L of solution
- $\frac{\text{moles of solute}}{\text{liter of solution}}$

Example of Calculating Molarity

What is the molarity of 0.500 L of a NaOH solution if it contains 6.00 g of NaOH?

STEP 1 State the given and needed quantities.

Given 6.00 g of NaOH in 0.500 L of solution

Need molarity (M)

STEP 2 Write a plan to calculate molarity.

molarity (M) = $\frac{\text{moles of solute}}{\text{liters of solution}}$

grams of NaOH ⟶ moles of NaOH ⟶ molarity

Example of Calculating of Molarity (continued)

STEP 3 Write equalities and conversion factors needed.

1 mol of NaOH = 40.01 g of NaOH

$\frac{1 \text{ mol NaOH}}{40.01 \text{ g NaOH}}$ and $\frac{40.01 \text{ g NaOH}}{1 \text{ mol NaOH}}$

STEP 4 Set up problem to calculate molarity.

$$6.00 \text{ g NaOH} \times \frac{1 \text{ mol NaOH}}{40.01 \text{ g NaOH}} = 0.150 \text{ mol of NaOH}$$

$$\frac{0.150 \text{ mol NaOH}}{0.500 \text{ L solution}} = \frac{0.300 \text{ mol}}{1 \text{ L}}$$

= 0.300 M NaOH solution

Learning Check

What is the molarity of 325 mL of a solution containing 46.8 g of $NaHCO_3$?

A. 0.557 M $NaHCO_3$ solution

B. 1.44 M $NaHCO_3$ solution

C. 1.71 M $NaHCO_3$ solution

Molarity Conversion Factors

The units of molarity are used as conversion factors in calculations with solutions.

TABLE 12.8 Examples of Molar Solutions and Conversion Factors

Molarity	Meaning	Conversion Factors
6.0 M HCl	6.0 mol of HCl in 1 L of solution	$\frac{6.0 \text{ mol HCl}}{1 \text{ L solution}}$ and $\frac{1 \text{ L solution}}{6.0 \text{ mol HCl}}$
0.20 M NaOH	0.20 mol of NaOH in 1 L of solution	$\frac{0.20 \text{ mol NaOH}}{1 \text{ L solution}}$ and $\frac{1 \text{ L solution}}{0.20 \text{ mol NaOH}}$

Example of Using Molarity in Calculations

How many grams of KCl are needed to prepare 0.125 L of a 0.720 M KCl solution?

STEP 1 State the given and needed quantities.

Given 0.125 L of a 0.720 M KCl solution

Need grams of KCl

STEP 2 Write a plan to calculate mass or volume.

liters of KCl solution ⟶ moles of KCl ⟶ grams of KCl

Example of Using Molarity in Calculations (continued)

STEP 3 Write equalities and conversion factors needed.

1 mol of KCl = 74.55 g of KCl

$\frac{1\text{ mol KCl}}{74.55\text{ g KCl}}$ and $\frac{74.55\text{ g KCl}}{1\text{ mol KCl}}$

1 L of KCl solution = 0.720 mol of KCl

$\frac{1\text{ L KCl solution}}{0.720\text{ mol KCl}}$ and $\frac{0.720\text{ mol KCl}}{1\text{ L KCl solution}}$

Example of Using Molarity in Calculations (continued)

STEP 4 Set up problem to calculate mass or volume.

$$0.125\ \text{L} \times \frac{0.720\ \text{mol KCl}}{1\ \text{L}} \times \frac{74.55\ \text{g KCl}}{1\ \text{mol KCl}} = 6.71\ \text{g of KCl}$$

Learning Check

How many grams of $AlCl_3$ are needed to prepare 37.8 mL of a 0.150 M $AlCl_3$ solution?

A. 0.00567 g of $AlCl_3$

B. 0.756 g of $AlCl_3$

C. 5.04 g of $AlCl_3$

Learning Check

How many milliliters of a 2.00 M HNO_3 solution contain 24.0 g of HNO_3?

A. 12.0 mL of HNO_3 solution

B. 83.3 mL of HNO_3 solution

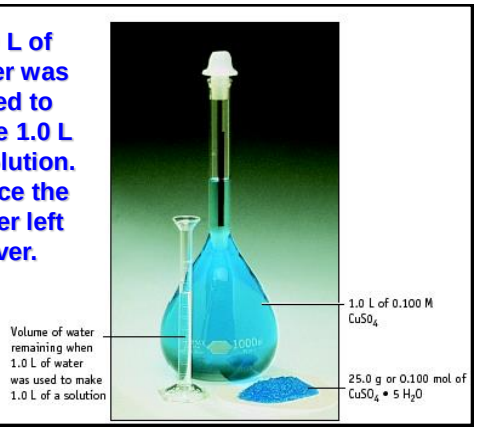
C. 190. mL of HNO_3 solution

Preparing a 6.0 M Solution

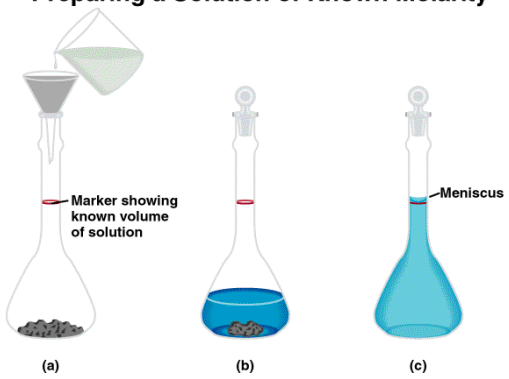
A 6.00 M NaOH solution is prepared

- by weighing out 60.0 g of NaOH (1.50 mol) and
- adding water to make 0.250 L of a 6.00 MNaOH solution

1.0 L of water was used to make 1.0 L of solution. Notice the water left over.



Preparing a Solution of Known Molarity

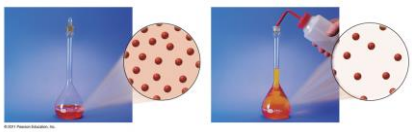


Practice

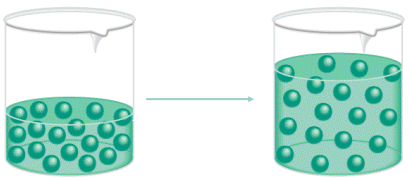
- Explain how to prepare 100 mL of a 0.150 *M* potassium permanganate solution.

Dilution

- Not all solutes come as solids that can be massed. Some compounds, along with most acids, come as concentrated solutions that must be diluted.
- Dilution is the process of adding water to a more concentrated solution to make a solution of lower concentration.



Dilution



Moles of solute before dilution (i) = **Moles of solute after dilution (f)**

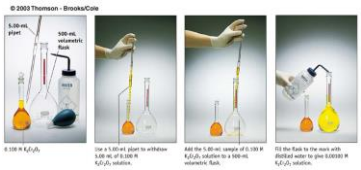
$M_i V_i = M_f V_f$

Comparing Initial and Diluted Solutions

In the initial and diluted solution,

- the moles of solute are the same
- the concentrations and volumes are related by the equation

$$M_1V_1 = M_2V_2$$



Example of Dilution Calculations

What is the final molarity of the solution when 0.180 L of 0.600 M KOH is diluted to 0.540 L?

STEP 1 Prepare a table of the initial and diluted volumes and concentrations.

Initial Solution	Diluted Solution
M_1 = 0.600 M	$\mathbf{M_2}$ = ?
V_1 = 0.180 L	V_2 = 0.540 L

Example of Dilution Calculations (continued)

STEP 2 Solve the dilution expression for the unknown quantity.

$$M_1V_1 = \mathbf{M_2}V_2$$

$$\frac{M_1V_1}{V_2} = \frac{\mathbf{M_2}V_2}{V_2}$$

$$\mathbf{M_2} = \frac{M_1V_1}{V_2}$$

STEP 3 Set up the problem by placing known quantities in the dilution expression.

$$M_2 = \frac{M_1V_1}{V_2} = \frac{(0.600\ M)(0.180\ \cancel{L})}{0.540\ \cancel{L}} = 0.200\ M$$

Learning Check

What is the final volume, in milliliters, if 15.0 mL of a 1.80 M KOH solution is diluted to give a 0.300 M KOH solution?

A. 27.0 mL of 0.300 M KOH solution
B. 60.0 mL of 0.300 M KOH solution
C. 90.0 mL of 0.300 M KOH solution

Practice

- Explain how to dilute a solution of 2.00 *M* $MgSO_4$ with water to prepare 100.0 mL of aqueous 0.400 *M* $MgSO_4$?

Molarity in Chemical Reactions

In a **chemical reaction**,

- the **volume** and **molarity** of a solution are used to determine the moles of a reactant or product

$$\text{volume (}\cancel{L}\text{)} \times \text{molarity } \left(\frac{\text{mol}}{1\ \cancel{L}}\right) = \text{moles}$$

- if **molarity** (mol/L) and **moles** are given, the volume (L) can be determined

$$\cancel{\text{mol}} \times \frac{1\ \text{L}}{\cancel{\text{mol}}} = \text{volume (L)}$$

Example of Using Molarity in a Chemical Equation

How many milliliters of a 3.00 M HCl solution are needed to react with 4.85 g of $CaCO_3$?

$2HCl(aq) + CaCO_3(s) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

STEP 1 State the given and needed quantities.

Given 3.00 M HCl solution; 4.85 g of $CaCO_3$
Need volume in milliliters

STEP 2 Write a plan to calculate needed quantity or concentration.

grams of $CaCO_3 \longrightarrow$ moles of $CaCO_3 \longrightarrow$ moles of HCl $\longrightarrow$ milliliters of HCl

Example of Using Molarity in a Chemical Equation (continued)

STEP 3 Write equalities and conversion factors including mole-mole and concentration factors.

1 mol of $CaCO_3$ = 100.09 g of $CaCO_3$

$\frac{1 \text{ mol } CaCO_3}{100.09 \text{ g } CaCO_3}$ and $\frac{100.09 \text{ g } CaCO_3}{1 \text{ mol } CaCO_3}$

1 mol of $CaCO_3$ = 2 mol of HCl

$\frac{1 \text{ mol } CaCO_3}{2 \text{ mol HCl}}$ and $\frac{2 \text{ mol HCl}}{1 \text{ mol } CaCO_3}$

1000 mL of HCl solution = 3.00 mol of HCl

$\frac{1000 \text{ mL HCl solution}}{3.00 \text{ mol HCl}}$ and $\frac{3.00 \text{ mol HCl}}{1000 \text{ mL HCl solution}}$

Example of Using Molarity in a Chemical Equation (continued)

STEP 4 Set up problem to calculate needed quantity or concentration.

$$4.85 \text{ g } \cancel{CaCO_3} \times \frac{1 \text{ } \cancel{\text{mol } CaCO_3}}{100.09 \text{ g } \cancel{CaCO_3}} \times \frac{2 \text{ } \cancel{\text{mol HCl}}}{1 \text{ } \cancel{\text{mol } CaCO_3}}$$

$$\times \frac{1000 \text{ mL HCl}}{3.00 \text{ } \cancel{\text{mol HCl}}} = 32.3 \text{ mL of HCl solution}$$

Learning Check

How many milliliters of a 0.150 M Na_2S solution are needed to react with 18.5 mL of a 0.225 M $NiCl_2$ solution?

$NiCl_2(aq) + Na_2S(aq) \longrightarrow NiS(s) + 2NaCl(aq)$

A. 4.16 mL
B. 6.24 mL
C. 27.8 mL

Learning Check

How many liters of H_2 gas at STP are produced when 6.25 g of Zn react with 20.0 mL of a 1.50 M HCl solution?

$Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$

A. 4.28 L of H_2
B. 0.336 L of H_2
C. 0.168 L of H_2

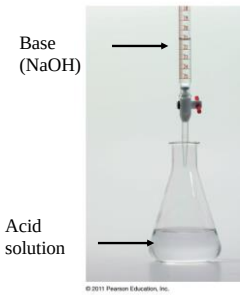
Titration

- Quantitative procedure where a solution of known concentration (**Standard Solution**) is used to react completely (to **equivalence point**) with a solution of unknown concentration.

Acid-Base Titration

Titration

- is a laboratory procedure used to determine the molarity of an acid
- uses a base such as NaOH to neutralize a measured volume of an acid



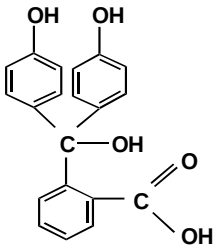
Indicator

An **indicator**

- is added to the acid in the flask
- changes the color of the solution when the acid is neutralized

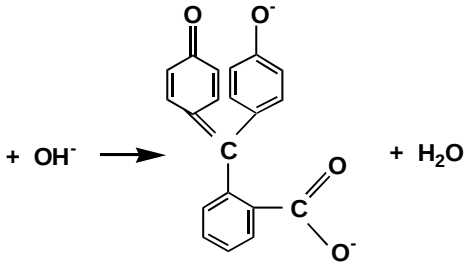
Indicators are molecules that react in such a way as to change color under different conditions

Phenolphthalein



colorless in acid

Phenolphthalein



pink in base

End Point of Titration

At the **end point**,

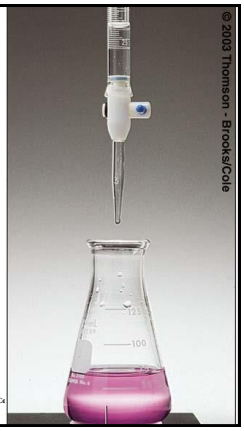
- the indicator has a permanent color
- the volume of the base used to reach the end point is measured
- the molarity of the acid is calculated using the neutralization equation for the reaction

Titration

- In acid-base titration, the **analyte**, which is the solution being analyzed, is a base and the titrant, which is the **standard solution** in the burette being added, is an acid, or visa versa.
- The **titrant** is added gradually to the analyte, until the reaction is just completed. This point is the stoichiometric point, or **equivalence** point.

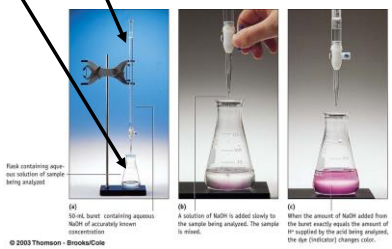
Titration

- Using the volume of the analyte, along with the volume and concentration of the titrant at the equivalence point, the concentration of the analyte can be determined from the stoichiometric ratio.



Titration Demo

$HCl_{(aq)} + NaOH_{(aq)} \rightarrow H_2O_{(l)} + Na^+_{(aq)} + Cl^-_{(aq)}$



Example of Calculating Molarity

What is the molarity of 10.0 mL of HCl solution if 18.5 mL of 0.225 M NaOH are required to neutralize the HCl?

$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$

STEP 1 State the given and needed quantities and concentration.

Given 18.5 mL of a 0.225 M NaOH solution
18.5 mL of NaOH = 0.0185 L of NaOH
10.0 mL of HCl = 0.0100 L of HCl

Need molarity of HCl solution

Calculating Molarity (continued)

STEP 2 Write a plan to calculate molarity.

L of NaOH ⟶ moles of NaOH ⟶ moles of HCl ⟶ molarity of HCl

STEP 3 State equalities and conversion factors including concentrations.

1 L of NaOH = 0.225 mol of NaOH

$\frac{1\text{ L NaOH}}{0.225\text{ mol NaOH}}$ and $\frac{0.225\text{ mol NaOH}}{1\text{ L NaOH}}$

1 mol of NaOH = 1 mol of HCl

$\frac{1\text{ mol HCl}}{1\text{ mol NaOH}}$ and $\frac{1\text{ mol NaOH}}{1\text{ mol HCl}}$

Calculating Molarity (continued)

STEP 4 Set up problem to calculate needed quantity.

$$0.0185\text{ L NaOH} \times \frac{0.225\text{ mol NaOH}}{1\text{ L NaOH}} \times \frac{1\text{ mol HCl}}{1\text{ mol NaOH}}$$

$= 0.00416$ mol of HCl

$$\text{Molarity of HCl} = \frac{0.00416\text{ mol HCl}}{0.0100\text{ L HCl}} = 0.416\text{ M HCl}$$

Learning Check

Calculate the milliliters of 2.00 M H_2SO_4 needed to completely neutralize 0.0500 L of 1.00 M KOH.

$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$

1) 12.5 mL
2) 50.0 mL
3) 200. mL

Learning Check

A 25.0 mL sample of phosphoric acid is neutralized by 42.6 mL of 1.45 M NaOH. What is the molarity of the phosphoric acid solution?

$3NaOH(aq) + H_3PO_4(aq) \longrightarrow Na_3PO_4(aq) + 3H_2O(l)$

1) 0.62 M
2) 0.841 M
3) 0.185 M