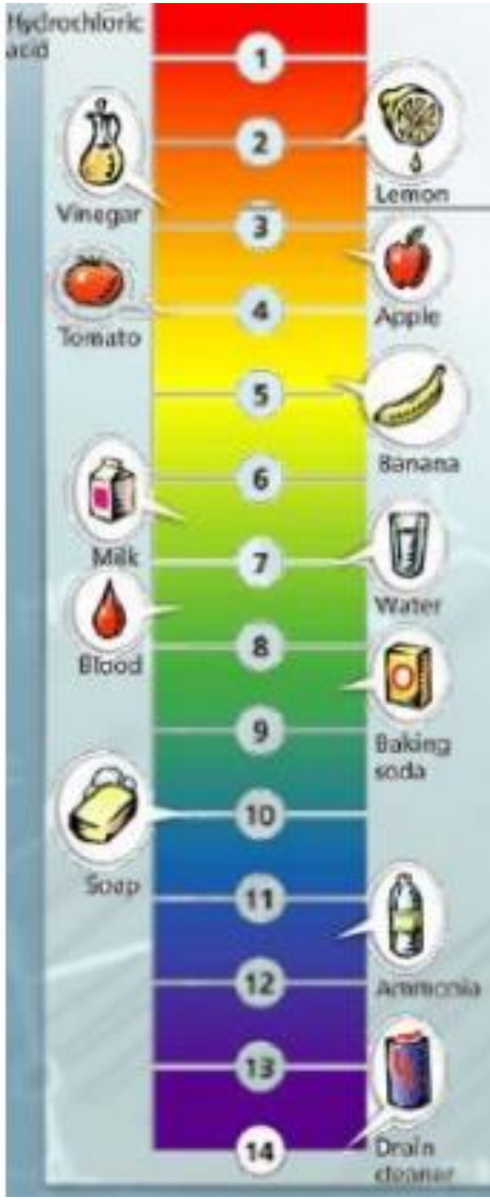
Calculations about Moles, Molarity & Molar Concentration

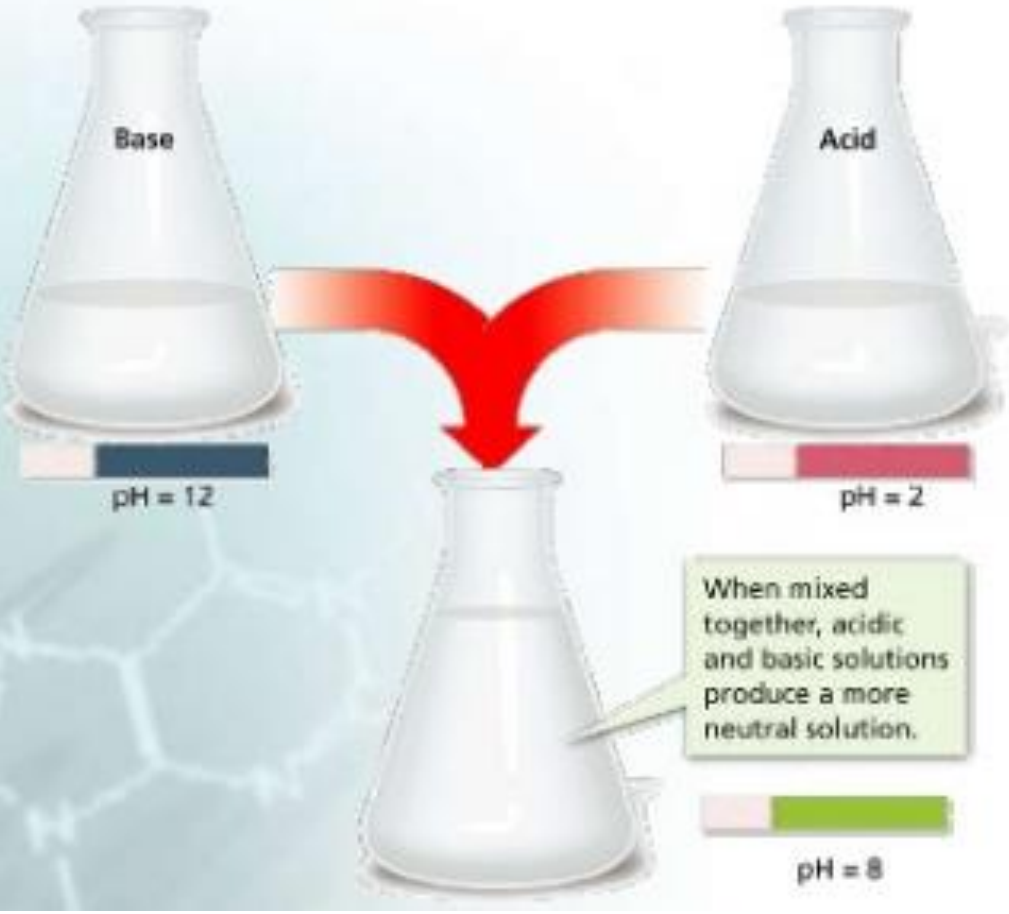


pH Scale

- **pH** is a measure of how acidic or basic a solution is.
- The pH scale ranges from 0 to 14.
- Acidic solutions have pH values below 7
- A solution with a pH of 0 is very acidic.
- A solution with a pH of 7 is neutral (water)
- Basic solutions have pH values above 7.

Acid – Base Reactions

A reaction between an acid and a base is called *neutralization*. An acid-base mixture is not as acidic or basic as the individual starting solutions.



All chemical reactions…

- have two parts:
  - **Reactants** = the substances you start with
  - **Products** = the substances you end up with
- The reactants will turn into the products.
- Reactants → Products

Symbols in Equations

- (s) after the formula = solid: $Fe_{(s)}$
- (g) after the formula = gas: $CO_{2(g)}$
- (l) after the formula = liquid: $H_2O_{(l)}$
- (aq) after the formula = dissolved in water, an aqueous solution: $NaCl_{(aq)}$ is a salt water solution

Symbols used in equations

- $\rightleftharpoons$ double arrow indicates a reversible reaction (more later)
- $\xrightarrow{\Delta}$, $\xrightarrow{\text{heat}}$ shows that heat is supplied to the reaction
- $\xrightarrow{\text{Pt}}$ is used to indicate a catalyst is supplied (in this case, platinum is the catalyst)

What is a catalyst?

- A substance that speeds up a reaction, without being changed or used up by the reaction.
- <u>Enzymes</u> are biological or protein catalysts in your body.

Balanced Chemical Equations

- According to the Law of Conservation of Mass: atoms aren't created or destroyed in a chemical reaction, they are just rearranged.
- All the atoms we *start with* in the reactants we must *end up with* in the products *(meaning: balanced!)*
- A balanced equation has the same number of each element *on both sides* of the equation.

Rules for balancing:

1) **Assemble the <u>correct formulas</u> for all the reactants and products, using "+" and "→"**

2) **Count the number of atoms of each type appearing on both sides**

3 **Balance the elements *one at a time* by adding *coefficients* (the numbers in front) where you need more - <u>save balancing the H and O until LAST!</u>**

(hint: I prefer to save O until the <u>*very*</u> last)

4 **<u>Double-Check</u> to make sure it is balanced.**

Never

- Never change a **subscript** to balance an equation (You can only change coefficients)
  - If you change the subscript (formula) you are describing a different chemical.
  - H_2O is a different compound than H_2O_2
- Never put a coefficient in the *middle* of a formula; they must go only in the front

2NaCl is okay, but Na2Cl is not.

Practice Balancing Examples

- $\_AgNO_3 + \_Cu \rightarrow \_Cu(NO_3)_2 + \_Ag$
- $\_Mg + \_N_2 \rightarrow \_Mg_3N_2$
- $\_P + \_O_2 \rightarrow \_P_4O_{10}$
- $\_Na + \_H_2O \rightarrow \_H_2 + \_NaOH$
- $\_CH_4 + \_O_2 \rightarrow \_CO_2 + \_H_2O$

Practice Balancing Examples

- $2AgNO_3 + \_Cu \rightarrow \_Cu(NO_3)_2 + 2Ag$
- $3Mg + \_N_2 \rightarrow \_Mg_3N_2$
- $4P + 5O_2 \rightarrow \_P_4O_{10}$
- $2Na + 2H_2O \rightarrow \_H_2 + 2NaOH$
- $\_CH_4 + 2O_2 \;\; \_CO_2 + 2H_2O$

#2 - Decomposition Reactions

- ***one reactant*** **breaks apart into two or more elements or compounds.**
- **the general equation is : AB → A + B**
- $H_2O \xrightarrow{\text{electricity}} H_2 + O_2$
- $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$
- $CuSO_4{\cdot}5H_2O \xrightarrow{\Delta} CuSO_4 + 5H_2O$

- $2NaHCO_{3(s)} \xrightarrow{\Delta} Na_2CO_{3(s)} + H_2O_{(l)} + CO_{2(g)}$
- **Note that *energy* (heat, sunlight, electricity, etc.) is usually required**

One mole of any substance contains the same number of particles.

What about the mass of a mole of a substance?

Is it same for all substances?

The mass of an element or compound depends on the mass of its particles.

Therefore, one mole of hydrogen has a mass dependent on it atomic mass. - MOLAR MASS

MOLAR MASS- the mass in grams that is numerically equal to the atomic mass. The unit of molar mass is grams / mole (g/mol).

WHAT IS THE ATOMIC MASS OF CARBON?

Answer: 12.01 amu

WHAT IS THE MOLAR MASS OF CARBON?

The molar mass of carbon is 12.01 g.

HOW MANY ATOMS ARE I 12.01G OF CARBON?

6.022 x 10^23 atoms

HOW MANY MOLES ARE THERE IN 70.9 G OF CHLORINE?

- Number of moles Cl = $\frac{\text{given mass}}{\text{molar mas}}$

$$= \frac{70.9\ \text{g}}{35.45\ \text{g/mol}}$$

$$= 2\ \text{mol}$$

To get the number of moles of a substance:

$$\text{Number of moles} = \frac{\text{given mass}}{\text{molar mass}}$$

HOW MANY NUMBER OF MOLES IN 36.04 G OF WATER?

1. Find the molar mass of water.

   a. Multiply the atomic mass of H by 2 and that of O by 1.

$$H = 2 \times 1.008 = 2.016$$

$$O = 1 \times 16.00 = \underline{16.00}$$

$$18.016 \text{ or } 18.02$$

$$\text{Number of moles (H2O)} = \frac{36.04\ g}{18.02\ g/mol}$$

$$= 2.0\ mol$$

A. Determine the molar masses of the following:

1. acetic acid (CH_3COOH)
2. agua oxigenada (H_2O_2)
3. ammonia (NH_3)

A. 1. CH_3COOH

$$
\begin{array}{l}
C = 2\times 12.01 = 24.02\ g/mol \\
H = 4\times 1.00 = 4.00\ g/mol \\
O = 2\times 16.00 = 32.02\ g/mol \\
\hline
\qquad\qquad 60.05\ g/mol
\end{array}
$$

2. H_2O_2

$$
\begin{array}{l}
H = 2\times 1.00 = 2.00\ g/mol \\
O = 2\times 16.00 = 32.00\ g/mol \\
\hline
\qquad\qquad 34.00\ g/mol
\end{array}
$$

3. NH_3

$$
\begin{array}{l}
N = 1\times 14.01 = 14.01\ g/mol \\
H = 3\times 3.02 = 3.00\ g/mol \\
\hline
\qquad\qquad 17.01\ g/mol
\end{array}
$$

B. Determine the number of moles in

1. 120.0 g of acetic acid
2. 17.0 g of agua oxigenada
3. 51.0 g of ammonia

B. 1. $$\text{mol acetic acid} = \frac{\text{given mass}}{\text{molar mass}} = \frac{120.0\ \text{g}}{60.05\ \text{g/mol}} = 2.00\ \text{mol}$$

2. $$\text{mol agua oxigenada} = \frac{17.0\ \text{g}}{34.00\ \text{g/mol}} = 0.50\ \text{mol}$$

3. $$\text{mol ammonia} = \frac{51.0\ \text{g}}{17.01\ \text{g/mol}} = 3.00\ \text{mol}$$

What is concentration?

The concentration of a solution expresses the amount of solute present in a given amount of solution. The terms concentrated and dilute are just relative expressions. A concentrated solution has more solute in it than a dilute solution; however, this does not give any indication of the exact amount of solute present. Therefore, we need more exact, quantitative methods of expressing concentration.

Concentration

- Measure of the amount of solute in a given amount of solvent or solution
  - Solutions
    - Dilute or concentrated
      - Dilute – relatively small amount of solute in a solvent
      - Concentrated – relatively large amount of solute in a solvent
- Measure of the amount of solute in a given

Molarity

- Number of moles of solute in one liter of solution
  - M - Symbol
  - Written as 1 M NaOH
    - One molar solution of sodium hydroxide
      - One mole NaOH in 1 liter of solution

$$\text{molarity} = \frac{\text{amount of solute (mol)}}{\text{volume of solution (L)}}$$

Units are mol/L

Molarity (M)

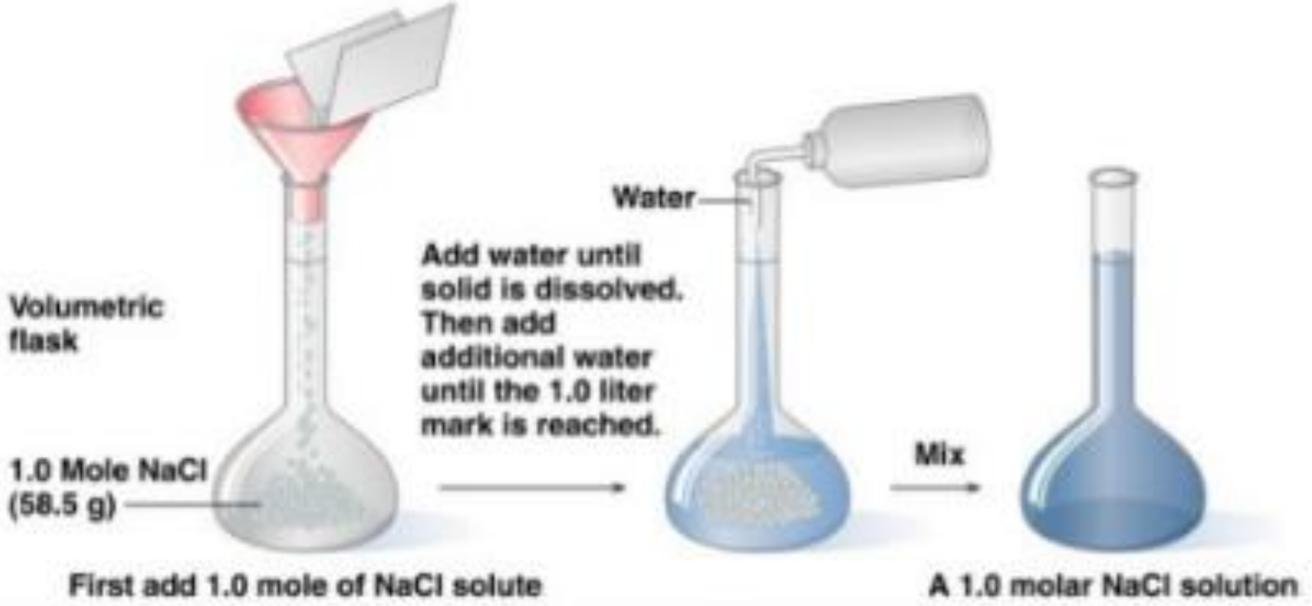
Molarity (M)

- Is a concentration term for solutions.
- Gives the moles of solute in 1 L solution.
- $= \dfrac{\text{moles of solute}}{\text{liter of solution}}$

Preparing a 1.0 Molar Solution

A 1.00 M NaCl solution is prepared

- By weighing out 58.5 g NaCl (1.00 mole) and
- Adding water to make 1.00 liter of solution.



Calculation of Molarity

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

STEP 1 **Given** 6.00 g NaOH in 0.500 L solution
Need molarity (mole/L)

STEP 2 **Plan** g NaOH ➡ mole NaOH ➡ molarity

Calculation of Molarity (cont.)

STEP 3 Conversion factors 1 mole NaOH = 40.0 g

$$\frac{1\ \text{mole NaOH}}{40.0\ \text{g NaOH}} \quad \text{and} \quad \frac{40.0\ \text{g NaOH}}{1\ \text{mole NaOH}}$$

STEP 4 Calculate molarity.

$$6.00\ \cancel{\text{g NaOH}} \times \frac{1\ \text{mole NaOH}}{40.0\ \cancel{\text{g NaOH}}} = 0.150\ \text{mole}$$

$$\frac{0.150\ \text{mole}}{0.500\ \text{L}} = \frac{0.300\ \text{mole}}{1\ \text{L}} = 0.300\ \text{M NaOH}$$

Learning Check

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

1) 0.557 M
2) 1.44 M
3) 1.71 M

Solution

3) 1.71 M

$$46.8\ \cancel{g\ NaHCO_3} \times \frac{1\ mole\ NaHCO_3}{84.0\ \cancel{g\ NaHCO_3}} = 0.557\ mole\ NaHCO_3$$

$$\frac{0.557\ mole\ NaHCO_3}{0.325\ L} = 1.71\ M\ NaHCO_3$$

Learning Check

What is the molarity of 225 mL of a KNO_3 solution containing 34.8 g KNO_3?

1) 0.344 M
2) 1.53 M
3) 15.5 M

Solution

2) 1.53 M

$$34.8 \text{ g } \cancel{KNO_3} \times \frac{1 \text{ mole } KNO_3}{101.1 \text{ } \cancel{\text{g } KNO_3}} = 0.344 \text{ mole } KNO_3$$

$$M = \frac{\text{mole}}{L} = \frac{0.344 \text{ mole } KNO_3}{0.225 \text{ L}} = 1.53 \text{ M}$$

~~n one setup~~

$$34.8 \text{ g } KNO_3 \times \frac{1 \text{ } \cancel{\text{mole } KNO_3}}{101.1 \text{ g } KNO_3} \times \frac{1}{0.225 \text{ L}} = 1.53 \text{ M}$$

Molarity Conversion Factors

The units of molarity are used to write conversion factors for calculations with solutions.

TABLE 8.10 **Some Examples of Molar Solutions**

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

Calculations Using Molarity

How many grams of KCl are needed to prepare 125 mL of a 0.720 M KCl solution?

STEP 1 **Given** 125 mL (0.125 L) of 0.720 M KCl

Need Grams of KCl

STEP 2 **Plan** L KCl $\Rightarrow$ moles KCl $\Rightarrow$ g KCl

Calculations Using Molarity

STEP 3 Conversion factors

1 mole KCl = 74.6 g

$$\frac{1 \text{ mole KCl}}{74.6 \text{ g KCl}} \quad \text{and} \quad \frac{74.6 \text{ g KCl}}{1 \text{ mole KCl}}$$

1 L KCl = 0.720 mole KCl

$$\frac{1 \text{ L}}{0.720 \text{ mole KCl}} \quad \text{and} \quad \frac{0.720 \text{ mole KCl}}{1 \text{ L}}$$

STEP 4 Calculate g KCl

$$0.125 \cancel{\text{L}} \times \frac{0.720 \cancel{\text{mole KCl}}}{1 \cancel{\text{L}}} \times \frac{74.6 \text{ g KCl}}{1 \cancel{\text{mole KCl}}} = 6.71 \text{ g KCl}$$

Learning Check

How many grams of $AlCl_3$ are needed to prepare 125 mL of a 0.150 M solution?

1) 20.0 g $AlCl_3$
2) 16.7g $AlCl_3$
3) 2.50 g $AlCl_3$

Solution

3) 2.50 g $AlCl_3$

$$0.125\ \cancel{L} \times \frac{0.150\ \cancel{mole}}{1\ \cancel{L}} \times \frac{133.5\ g}{\cancel{1}\ mole} = 2.50\ g\ AlCl_3$$

Learning Check

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

1) 12.0 mL
2) 83.3 mL
3) 190. mL

Solution

$$24.0\ g\ \cancel{HNO_3} \times \frac{1\ \cancel{mole\ HNO_3}}{63.0\ g\ \cancel{HNO_3}} \times \frac{1000\ mL}{2.00\ \cancel{moles\ HNO_3}} =$$

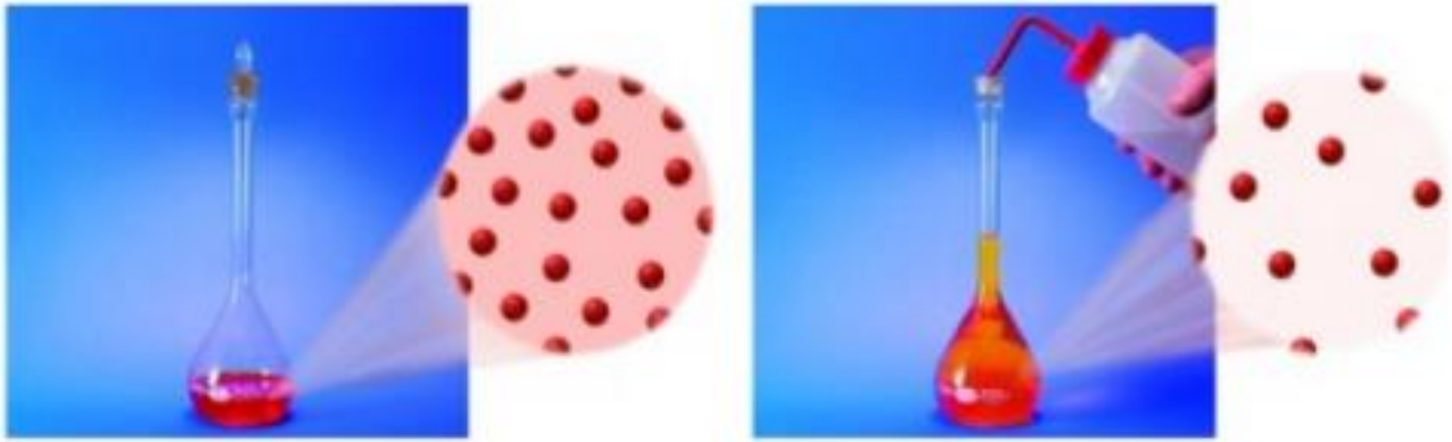
Molarity factor inverted

$$= \ 190.\ mL\ HNO_3$$

Dilution

In a dilution,

- Water is added.
- Volume increases.
- Concentration decreases.



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 following equations:

For percent concentration

$$C_1V_1 = C_2V_2$$

initial *diluted*

For molarity

$$M_1V_1 = M_2V_2$$

initial *diluted*

Dilution Calculations with Percent

What volume of a 2.00 %(m/v) HCl solution can be prepared by diluting 25.0 mL of 14.0%(m/v) HCl solution?

Prepare a table:

$C_1 =$ 14.0 %(m/v) V_1 = 25.0 mL

$C_2 =$ 2.00%(m/v) V_2 = ?

Solve dilution equation for unknown and enter values:

$$C_1V_1 = C_2V_2$$

$$V_2 = \frac{V_1C_1}{C_2} = \frac{(25.0\ \text{mL})(14.0\%)}{2.00\%} = 175\ \text{mL}$$

What is the percent (%m/v) of a solution prepared by diluting 10.0 mL of 9.00% NaOH to 60.0 mL?

Solution

What is the percent (%m/v) of a solution prepared by diluting 10.0 mL of 9.00% NaOH to 60.0 mL?

Prepare a table:

$C_1 =$ 9.00 %(m/v)	V_1 = 10.0 mL
$C_2 =$?	V_2 = 60.0 mL

Solve dilution equation for unknown and enter values:

$$C_1V_1 = C_2V_2$$

$$C_2 = \frac{C_1 V_1}{V_2} = \frac{(10.0\ \text{mL})(9.00\%)}{60.0\ \text{mL}} = 1.50\ \%(\text{m/v})$$

Dilution Calculations

What is the molarity (M) of a solution prepared by diluting 0.180L of 0.600 M HNO_3 to 0.540 L?

Prepare a table:

$M_1 = 0.600\ M \qquad V_1 = 0.180\ L$

$M_2 = ? \qquad V_2 = 0.540\ L$

Solve dilution equation for unknown and enter values:

$M_1V_1 = M_2V_2$

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

Learning Check

What is the final volume (mL) of 15.0 mL of a 1.80 M KOH diluted to give a 0.300 M solution?

1) 27.0 mL
2) 60.0 mL
3) 90.0 mL

Solution

What is the final volume (mL) of 15.0 mL of a 1.80 M KOH diluted to give a 0.300 M solution?

Prepare a table:

$M_1 = 1.80\ M \qquad V_1 = 15.0\ mL$

$M_2 = 0.300\ M \qquad V_2 = ?$

Solve dilution equation for V_2 and enter values:

$$M_1V_1 = M_2V_2$$

$$V_2 = \frac{M_1V_1}{M_2} = \frac{(1.80\ \cancel{M})(15.0\ mL)}{0.300\ \cancel{M}} = 90.0\ mL$$

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.

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

- If molarity (mole/L) and moles are given, the volume (L) can be determined

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

Using Molarity of Reactants

How many mL of 3.00 M HCl are needed to completely react with 4.85 g $CaCO_3$?

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

STEP 1 Given 3.00 M HCl; 4.85 g $CaCO_3$

Need volume in mL

STEP 2 Plan

g $CaCO_3$ ➡ mole $CaCO_3$ ➡ mole HCl ➡ mL HCl

Using Molarity of Reactants (cont.)

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

STEP 3 Equalitites

1 mole $CaCO_3$ = 100.1 g;   1 mole $CaCO_3$ = 2 mole HCl

1000 mL HCl = 3.00 mole HCl

STEP 4 Set Up

$$4.85\ \cancel{\text{g } CaCO_3} \times \frac{1\ \cancel{\text{mole } CaCO_3}}{100.1\ \cancel{\text{g } CaCO_3}} \times \frac{2\ \cancel{\text{mole HCl}}}{1\ \cancel{\text{mole } CaCO_3}} \times \frac{1000\ \text{mL HCl}}{3.00\ \cancel{\text{mole HCl}}}$$

= 32.3 mL HCl required

Learning Check

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

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

1) 4.16 mL
2) 6.24 mL
3) 27.8 mL

Solution

3) 27.8 mL

$$0.0185\ \cancel{L} \times \frac{0.225\ \cancel{\text{mole NiCl}_2}}{1\ \cancel{L}} \times \frac{1\ \cancel{\text{mole Na}_2\text{S}}}{1\ \cancel{\text{mole NiCl}_2}} \times \frac{1000\ \text{mL}}{0.150\ \cancel{\text{mole Na}_2\text{S}}}$$

$= 27.8\ \text{mL}\ Na_2S$ solution

Learning Check

If 22.8 mL of 0.100 M $MgCl_2$ is needed to completely react 15.0 mL of $AgNO_3$ solution, what is the molarity of the $AgNO_3$ solution?

$$MgCl_2(aq) + 2AgNO_3(aq) \longrightarrow 2AgCl(s) + Mg(NO_3)_2(aq)$$

1) 0.0760 M
2) 0.152 M
3) 0.304 M

Solution

3) 0.304 M $AgNO_3$

$$0.0228\ \cancel{L} \times \frac{0.100\ \cancel{\text{mole MgCl}_2}}{1\ \cancel{L}} \times \frac{2\ \text{moles AgNO}_3}{1\ \cancel{\text{mole MgCl}_2}} \times \frac{1}{0.0150\ L}$$

$= 0.304\ \text{mole/L} = 0.304\ M\ AgNO_3$

Learning Check

How many liters of H_2 gas at STP are produced when Zn react with 125 mL of 6.00 M HCl?

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

1) 4.20 L H_2
2) 8.40 L H_2
3) 16.8 L H_2

Solution

2) 8.40 L H_2 gas

$$0.125\,\cancel{L} \times \frac{6.00\ \cancel{\text{moles HCl}}}{1\,\cancel{L}} \times \frac{1\ \cancel{\text{mole } H_2}}{2\ \cancel{\text{moles HCl}}} \times \frac{22.4\ L}{1\ \cancel{\text{mole } H_2}}$$

$$= 8.40\ L\ H_2 \text{ gas}$$

Molality

- Concentration of a solution expressed in moles of solute per kilogram of solvent.
  - m - symbol
  - Written as 1 m solution of NaOH
    - One molal solution of sodium hydroxide
      - 1 mol NaOH in 1 kg of solvent

$$\text{molality} = \frac{\text{moles solute (mol)}}{\text{mass of solvent (Kg)}}$$