Chapter 6

Solutions to Supplementary *Check for Understanding* Problems

Formation of Aqueous Solutions

1. A teaspoon of salt will readily dissolve in a pot of water. What happens to the salt concentration as the solution boils? Explain.

Solution

The salt solution increases. As the water boils the solution volume decreases while the amount of the salt does not change. This means there is more salt per liter of solution which represents a higher salt concentration.

2. Describe how an ionic compound dissolves in water. How are the strong electrostatic forces in the ionic solid overcome? How are the dissolved cations and anions prevented from recombining to form the solid?

Solution

When an ionic compound dissolves in water the cations and anions become separated and the individual ions are surrounded by water molecules. The initial electrostatic attractions between cations and anions are overcome by the electrostatic attractions of the ions to many polar water molecules. The dissolved ions are surrounded by layers of water molecules which limit the ability of the cations and anions to interact and reform the solid.

3. Use the model for an ionic compound dissolving in water to explain why smaller solute particles dissolve faster than large ones.

Solution

When an ionic compound dissolves in water only the cations and anions on the surface of the particles of the solute interact with polar water molecules and eventually become separated and surrounded by solvent. For a given amount of solute, as large particles are broken up into smaller ones new surfaces are exposed and there is an increase in the overall surface area which can interact with the water solvent so these smaller particles dissolve faster than larger ones.

4. Why is a concentrated solution of an ionic compound a good conductor of electricity?

Solution

Electrical conductivity involves the movement of electric charges in the form of ions or electrons A concentrated solution of an ionic compound has many dissolved ions. This large number of mobile charges enables such a solution to conduct electricity readily.

5. Why is a sugar solution a very poor conductor of electricity?

Solution

When sugar dissolves the sugar molecules become separated and surrounded by water molecules. However, there are no mobile charges created so the solution does not conduct electricity readily.

6. What does the label “concentrated HNO_3" on a bottle mean?

Solution

A solution labeled concentrated HNO_3 means that there is a large number of (often the maximum number of) moles of solute (HNO_3) per liter of solution.

Solution Mass Percent

1. An aqueous NaCl solution that is 3.2% by mass NaCl contains __________ g NaCl for every __________ g water.

Answers: 3.2 g NaCl
96.8 g H_2O

Solution

Recall that $\text{solute mass}\,\% = \dfrac{\text{solute mass}}{100\,\text{g solution}} = \dfrac{\text{solute mass}}{\text{solvent mass} + \text{solute mass}}$

Therefore, in 100 g solution there will be 3.2 g NaCl and 96.8 g H_2O.

2. Calculate the mass in grams of KCl in 18.6 g of a solution that is 0.15% KCl by mass.

Answer: 0.28 g

Solution

What we know: g solution; g KCl/100 g solution

Desired answer: g KCl

The solution map for this problem is:

g solution ➔ g KCl

Remember that the mass percent of KCl refers to the g of KCl per 100 g of solution. This is exactly the conversion factor needed for this calculation. Applying this yields:

$$18.6 \cancel{\text{g soln}} \times \frac{0.15 \text{ g KCl}}{100 \cancel{\text{g soln}}} = 0.028 \text{ g KCl}$$

3. What mass of a solution that is 4.8% by mass $NaHCO_3$ is needed to obtain 75 g $NaHCO_3$?

Answer: 1.6×10^3 g

Solution

What we know: g $NaHCO_3$; g $NaHCO_3$/100 g solution

Desired answer: g solution

The solution map for this problem is:

g $NaHCO_3$ ➔ g solution

The conversion factor needed for this calculation is the mass % in the form $\frac{100 \text{ g solution}}{4.8 \text{ g } NaHCO_3}$.

Applying this yields:

$$75 \cancel{\text{g } NaHCO_3} \times \frac{100 \text{ g solution}}{4.8 \cancel{\text{g } NaHCO_3}} = 1.6 \times 10^3 \text{ g solution}$$

Molarity

1. Which of the following are needed to calculate the molarity of an aqueous solution? Select all that apply. Explain your answer.

   A. the mass of the solute

   B. the molar mass of the solute

   C. the volume of water added

   D. the total volume of the solution

   E. the solution density

Answer: A, B and D

Solution

Solute molarity is calculated by: $\dfrac{\text{mol solute}}{\text{soln volume (L)}} = \dfrac{\dfrac{\text{mass solute}}{\text{molar mass solute}}}{\text{soln volume (L)}}$. Therefore, the information indicated in A, B and D is needed.

2. What is the sodium ion molarity in a 0.115 M Na_3PO_4 solution?

Answer: 0.345 M

Solution

What we know: mol Na_3PO_4/L solution

Desired answer: mol Na^+/L solution

The solution map for this calculation is:

$$\frac{\text{mol } Na_3PO_4}{\text{L soln}} \rightarrow \frac{\text{mol } Na^+}{\text{L soln}}$$

The formula of the solute indicates that in 1 mole of sodium phosphate there are 3 moles of sodium ions. This relationship can be applied as follows.

$$\frac{0.115\ \cancel{\text{mol Na}_3\text{PO}_4}}{\text{L soln}} \times \frac{3\ \text{mol Na}^+}{1\ \cancel{\text{mol Na}_3\text{PO}_4}} = \frac{0.345\ \text{mol Na}^+}{\text{L soln}} = 0.345\ \text{M Na}^+$$

3. What is the molarity of a solution prepared from 5.62 g NH_4NO_3 dissolved in water and diluted to 125 mL?

Answer: 0.562 M

Solution

What we know: g NH_4NO_3; mL solution

Desired answer: mol NH_4NO_3/L solution

The solution map for this calculation is:

$$\frac{\text{g NH}_4\text{NO}_3}{\text{mL soln}} \rightarrow \frac{\text{mol NH}_4\text{NO}_3}{\text{mL soln}} \rightarrow \frac{\text{mol NH}_4\text{NO}_3}{\text{L soln}}$$

The conversion factor needed in the first step is the molar mass of NH_4NO_3 in the form $\frac{1\ \text{mol NH}_4\text{NO}_3}{80.05\ \text{g NH}_4\text{NO}_3}$.

The conversion factor for the second step is $\frac{1\ \text{mL soln}}{10^{-3}\ \text{L soln}}$.

Putting these together yields:

$$\frac{5.62\ \cancel{\text{g NH}_4\text{NO}_3}}{125\ \cancel{\text{mL soln}}} \times \frac{1\ \text{mol NH}_4\text{NO}_3}{80.05\ \cancel{\text{g NH}_4\text{NO}_3}} \times \frac{1\ \cancel{\text{mL soln}}}{10^{-3}\ \text{L soln}} = \frac{0.562\ \text{mol NH}_4\text{NO}_3}{\text{L soln}}$$

4. What volume (in mL) of a 0.204 M NaOH solution contains 8.53 g NaOH?

Answer: 1.05×10^3 mL

Solution

What we know: g NaOH; mol NaOH/1000 mL solution

Desired answer: mL solution

The solution map for this calculation is:

g NaOH ➔ mol NaOH ➔ mL solution

The conversion factor needed in the first step is the molar mass of NaOH in the form $\dfrac{1\,\text{mol NaOH}}{40.00\,\text{g NaOH}}$.

The conversion factor needed in the second step is the solution concentration in the form $\dfrac{1000\,\text{mL soln}}{0.204\,\text{mol NaOH}}$.

Putting these together yields:

$$8.53\,\cancel{\text{g NaOH}} \times \frac{1\,\cancel{\text{mol NaOH}}}{40.00\,\cancel{\text{g NaOH}}} \times \frac{1000\,\text{mL soln}}{0.204\,\cancel{\text{mol NaOH}}} = 1.05 \times 10^{3}\,\text{mL soln}$$

5. How many moles of NaF are present in 22.9 mL of a 5.16 mM NaF solution?

Answer: 1.18×10^{-4} mol

Solution

What we know: mL solution; mmol NaF/1000 mL solution

Desired answer: mol NaF

The solution map for this calculation is:

mL solution ➔ mmol NaF ➔ mol NaF

The conversion factor needed in the first step is the solution concentration in the form $\dfrac{5.16\,\text{mmol NaF}}{1000\,\text{mL soln}}$.

The conversion factor needed in the second step is $\dfrac{10^{-3}\,\text{mol NaF}}{1\,\text{mmol NaF}}$.

Putting these together yields:

$$22.9\ \text{mL soln} \times \frac{5.16\ \text{mmol NaF}}{1000\ \text{mL soln}} \times \frac{10^{-3}\ \text{mol NaF}}{1\ \text{mmol NaF}} = 1.18 \times 10^{-4}\ \text{mol NaF}$$

6. What mass of $Na_2C_2O_4$ is needed to prepare 75.0 mL of a 0.226 M $Na_2C_2O_4$ solution?

Answer: 2.27 g

<u>Solution</u>

What we know: mL solution; mol $Na_2C_2O_4$/1000 mL solution

Desired answer: g $Na_2C_2O_4$ needed

The solution map for this problem is:

mL solution ➔ mol $Na_2C_2O_4$ ➔ g $Na_2C_2O_4$

The conversion factor needed in the first step is the solution concentration in the form $\frac{0.226\ \text{mol}\ Na_2C_2O_4}{1000\ \text{mL soln}}$.

The conversion factor needed in the second step is the molar mass of $Na_2C_2O_4$ in the form $\frac{134.00\ \text{g}\ Na_2C_2O_4}{1\ \text{mol}\ Na_2C_2O_4}$.

Putting these together yields:

$$75.0\ \text{mL soln} \times \frac{0.226\ \text{mol}\ Na_2C_2O_4}{1000\ \text{mL soln}} \times \frac{134.00\ \text{g}\ Na_2C_2O_4}{1\ \text{mol}\ Na_2C_2O_4} = 2.27\ \text{g}\ Na_2C_2O_4$$

7. What is the nitrate ion molarity in a solution prepared from 26.8 mg aluminum nitrate dissolved in water and diluted to 0.750 L?

Answer: 5.03×10^{-4} M

Solution

What we know: mg $Al(NO_3)_3$; L solution

Desired answer: mol NO_3^-/L solution

The solution map for this calculation is:

$$\frac{\text{mg Al(NO}_3)_3}{\text{L soln}} \rightarrow \frac{\text{g Al(NO}_3)_3}{\text{L soln}} \rightarrow \frac{\text{mol Al(NO}_3)_3}{\text{L soln}} \rightarrow \frac{\text{mol NO}_3^-}{\text{L soln}}$$

The conversion factor needed in the first step is $\frac{10^{-3}\text{ g Al(NO}_3)_3}{1\text{ mg Al(NO}_3)_3}$.

The conversion factor needed in the second step is the molar mass of $Al(NO_3)_3$ in the form $\frac{1\text{ mol Al(NO}_3)_3}{213.01\text{ g Al(NO}_3)_3}$.

The conversion factor for the last step is $\frac{3\text{ mol NO}_3^-}{1\text{ mol Al(NO}_3)_3}$.

Putting these together yields:

$$\frac{26.8\text{ mg Al(NO}_3)_3}{0.750\text{ L soln}} \times \frac{10^{-3}\text{ g Al(NO}_3)_3}{1\text{ mg Al(NO}_3)_3} \times \frac{1\text{ mol Al(NO}_3)_3}{213.01\text{ g Al(NO}_3)_3} \times \frac{3\text{ mol NO}_3^-}{1\text{ mol Al(NO}_3)_3} = \frac{5.03 \times 10^{-4}\text{ mol NO}_3^-}{\text{L soln}}$$

8. What is the density of a 15.8 M HNO_3 aqueous solution if it is 70.4% by mass HNO_3?

Answer: 1.41 g/mL

Solution

What we know: mol HNO_3/1000 mL solution; g HNO_3/100 g solution

Desired answer: g solution/mL solution

The solution map for this problem is:

$$\frac{\text{mol HNO}_3}{\text{mL soln}} \rightarrow \frac{\text{g HNO}_3}{\text{mL soln}} \rightarrow \frac{\text{g soln}}{\text{mL soln}}$$

The conversion factor needed in the first step is the molar mass of HNO_3 in the form
$\frac{63.02\text{ g HNO}_3}{1\text{ mol HNO}_3}$.

The conversion factor needed in the second step is the solute mass percent in the form
$\frac{100\text{ g soln}}{70.4\text{ g HNO}_3}$.

Putting these together yields:

$$\frac{15.8\ \cancel{\text{mol HNO}_3}}{1000\text{ mL soln}} \times \frac{63.02\ \cancel{\text{g HNO}_3}}{1\ \cancel{\text{mol HNO}_3}} \times \frac{100\text{ g soln}}{70.4\ \cancel{\text{g HNO}_3}} = \frac{1.41\text{ g soln}}{\text{mL soln}}$$

<u>Dilutions</u>

1. Explain why the equation $M_1V_1 = M_2V_2$ works for solving dilution problems.

<u>Solution</u>

When a solution is diluted the number of moles of solute remains constant while the solution volume increases, thus leading to a decrease in solute concentration. The number of moles of solute equals its molarity (M) times the solution volume (V) so the starting number of solute moles ($M_1V_{1)}$ will equal the moles of solute after dilution (M_2V_2).

2. If a salt solution is diluted by adding a volume of water equal to 50% of the solution volume, by what factor has the salt concentration been diluted? Assume that the volumes are additive.

Answer: 2/3

<u>Solution</u>

What we know: relationship between the initial volume and final volume

Desired answer: dilution factor (V_1/V_2)

Although no numerical value is given for V_1 or V_2 we know the relationship between the initial volume: $V_2 = V_1 + \frac{1}{2}V_1$. Substituting for V_2 in the dilution factor ratio yields:

$$\frac{V_1}{V_2} = \frac{V_1}{V_1 + \frac{1}{2}V_1} = \frac{\cancel{V_1}}{\frac{3}{2}\cancel{V_1}} = \frac{2}{3}$$

3. How many milliliters of 14.8 M H_3PO_4 are needed to prepare 2.50 L of 3.0 M H_3PO_4?

Answer: 507 mL

<u>Solution</u>

What we know: initial concentration of H_3PO_4 (M_1); final concentration of H_3PO_4 solution (M_2); final volume of H_3PO_4 solution (V_2)

Desired answer: initial volume of the more concentrated H_3PO_4 solution (V_1)

Note that this is a dilution problem. Solve the dilution equation for V_1. It is useful to first convert the final volume to milliliters.

$$2.50\,\cancel{L} \times \frac{1\,mL}{10^{-3}\,\cancel{L}} = 2.50 \times 10^{3}\,mL$$

$$V_1 = \frac{M_2V_2}{M_1} = \frac{\left(\frac{3.0\,\cancel{mol\,H_3PO_4}}{1000\,\cancel{mL\,dil\,soln}}\right)\left(2.50 \times 10^{3}\,\cancel{mL\,dil\,soln}\right)}{\left(\frac{14.8\,\cancel{mol\,H_3PO_4}}{1000\,mL\,conc\,soln}\right)} = 507\,mL\,conc\,soln$$

<u>Solution Stoichiometry</u>

1. Barium sulfate is an exception to the rule that sulfates tend to be soluble in water. How many milliters of 0.25 M Na_2SO_4 are needed to precipitate all of the barium as $BaSO_4$ from 10.0 mL of 0.15 M $Ba(NO_3)_2$?

$$Ba(NO_3)_2(aq) + Na_2SO_4(g) \rightarrow BaSO_4(s) + 2NaNO_3(aq)$$

Answer: 6.0 mL

Solution

What we know: mol Na_2SO_4/1000 mL solution; mL $Ba(NO_3)_2$ solution; mol $Ba(NO_3)_2$/1000 mL solution; balanced equation relating Na_2SO_4 and $Ba(NO_3)_2$

Desired answer: mL Na_2SO_4 solution

The solution map for this calculation is:

mL $Ba(NO_3)_2$ soln ➔ mol $Ba(NO_3)_2$ ➔ mol Na_2SO_4 ➔ mL Na_2SO_4 soln

The conversion factor needed in the first step is the $Ba(NO_3)_2$ solution concentration in the form $\frac{0.15\,\text{mol Ba(NO}_3)_3}{1000\,\text{mL Ba(NO}_3)_3\text{ soln}}$.

The conversion factor needed in the second step is the $Na_2SO_4/Ba(NO_3)_2$ mole ratio from the balanced equation.

The conversion factor in the last step is the Na_2SO_4 solution concentration in the form $\frac{1000\,\text{mL Na}_2\text{SO}_4\text{ soln}}{0.25\,\text{mol Na}_2\text{SO}_4}$

Putting these together yields:

$$10.0\,\cancel{\text{mL Ba(NO}_3)_2\text{ soln}} \times \frac{0.15\,\cancel{\text{mol Ba(NO}_3)_2}}{1000\,\cancel{\text{mL Ba(NO}_3)_2\text{ soln}}} \times \frac{1\,\cancel{\text{mol Na}_2\text{SO}_4}}{1\,\cancel{\text{mol Ba(NO}_3)_2}} \times \frac{1000\,\text{mL Na}_2\text{SO}_4\text{ soln}}{0.25\,\cancel{\text{mol Na}_2\text{SO}_4}} = 6.0\,\text{mL Na}_2\text{SO}_4\text{ soln}$$

2. If 35.0 mL of a 0.162 M $CaCl_2$ solution are added to 20.0 mL of 0.211 M Na_2CO_3, what is the maximum number of moles of $CaCO_3$ that can form?

Answer: 0.00422 mol

Solution

What we know: mol $CaCl_2$/1000 mL solution; mL $CaCl_2$ solution; mol Na_2CO_3/1000 mL solution; mL Na_2CO_3 solution;

Desired answer: maximum mol $CaCO_3$ produced

A balanced equation for this double displacement reaction is needed.

$$CaCl_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2NaCl(aq)$$

First determine the limiting reactant by calculating how many moles of $CaCO_3$ can possibly be produced from each starting amount of reactant. The solution maps for these calculations are:

mL $CaCl_2$ soln ➔ mol $CaCl_2$ ➔ mol $CaCO_3$

mL Na_2CO_3 soln ➔ mol Na_2CO_3 ➔ mol $CaCO_3$

For the first calculation the conversion factors needed are the molarity of the $CaCl_2$ solution and the $CaCO_3/CaCl_2$ mole ratio.

Putting these together yields:

$$35.0\ \cancel{\text{mL CaCl}_2\text{ soln}} \times \frac{0.162\ \cancel{\text{mol CaCl}_2}}{1000\ \cancel{\text{mL CaCl}_2\text{ soln}}} \times \frac{1\ \text{mol CaCO}_3}{1\ \cancel{\text{mol CaCl}_2}} = 0.00567\ \text{mol CaCO}_3$$

For the second calculation the conversion factors needed are the molarity of the Na_2CO_3 solution and the $CaCO_3/Na_2CO_3$ mole ratio.

Putting these together yields:

$$20.0\ \cancel{\text{mL } Na_2CO_3\text{ soln}} \times \frac{0.211\ \cancel{\text{mol } Na_2CO_3}}{1000\ \cancel{\text{mL } Na_2CO_3\text{ soln}}} \times \frac{1\ \text{mol CaCO}_3}{1\ \cancel{\text{mol } Na_2CO_3}} = 0.00422\ \text{mol CaCO}_3$$

Since the starting amount of Na_2CO_3 solution produces the smaller amount of $CaCO_3$, Na_2CO_3 is the limiting reactant and the maximum yield is 0.00422 mol $CaCO_3$.

Acid-Base Neutralizations

1. If 33.3 mL of 0.150 M HCl are needed to neutralize 0.0250 L of a NaOH solution, what is the molarity of the NaOH?

Answer: 0.200 M

Solution

What we know: mol HCl/1000 mL solution; mL HCl solution; mL NaOH solution

Desired answer: mol NaOH/L solution

A balanced equation for the neutralization reaction is needed.

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

The solution map for this calculation is:

$$\text{mL HCl soln} \rightarrow \text{mol HCl} \rightarrow \text{mol NaOH} \rightarrow \frac{\text{mol NaOH}}{\text{L soln}}$$

The conversion factor needed in the first step is the HCl solution concentration in the form $\frac{0.0984 \text{ mol KOH}}{1000 \text{ mL soln}}$.

The conversion factor needed in the second step is the NaOH/HCl mole ratio from the balanced equation.

Putting these together yields:

$$33.3 \cancel{\text{mL HCl soln}} \times \frac{0.150 \cancel{\text{mol HCl}}}{1000 \cancel{\text{mL HCl soln}}} \frac{1 \text{ mol NaOH}}{1 \cancel{\text{mol HCl}}} = 0.00500 \text{ mol NaOH}$$

The final step is:

$$\frac{0.00500 \text{ mol NaOH}}{0.0250 \text{ L soln}} = \frac{0.200 \text{ mol NaOH}}{\text{L soln}}$$

2. How many milliliters of 0.150 M HCl are needed to completely react 0.245 g Na_2CO_3?

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$$

Answer: 30.8 mL

Solution

What we know: mol HCl/1000 mL solution; g Na_2CO_3; balanced equation relating HCl and Na_2CO_3

Desired answer: mL HCl solution

The solution map for this calculation is:

$$\text{g } Na_2CO_3 \rightarrow \text{mol } Na_2CO_3 \rightarrow \text{mol HCl} \rightarrow \text{mL HCl soln}$$

The conversion factor needed in the first step is the molar mass of Na_2CO_3 in the form $\frac{1\,mol\,Na_2CO_3}{105.99\,g\,Na_2CO_3}$.

The conversion factor needed in the second step is the HCl/Na_2CO_3 mole ratio from the balanced equation.

The conversion factor needed in the last step is the HCl solution concentration in the form $\frac{1000\,mL\,soln}{0.150\,mol\,HCl}$.

Putting these together yields:

$$0.245\,\cancel{g\,Na_2CO_3} \times \frac{1\,\cancel{mol\,Na_2CO_3}}{105.99\,\cancel{g\,Na_2CO_3}} \times \frac{2\,\cancel{mol\,HCl}}{1\,\cancel{mol\,Na_2CO_3}} \times \frac{1000\,mL\,HCl\,soln}{0.150\,\cancel{mol\,HCl}} = 30.8\,mL\,HCl\,soln$$