Lesson 10 – Solutions and Concentration

Learning Objectives

In this lesson you will learn:

- To calculate the **mass percent composition** of a **solution**
- To calculate the **volume percent composition** of a solution
- To calculate the **content of a solution** from the mass percent composition
- To calculate the composition of a **saturated solution** of a compound at a given **temperature**
- To calculate the **solubility** of a compound from the mass percent composition of a saturated solution
- To calculate the **molarity** (molar concentration) of a solution
- To calculate the **molarity of each** ion in a solution
- To calculate the quantity of solute needed to make a solution of given (target) molarity
- To calculate the molarity of a solution after **dilution**
- To calculate the volume of **stock solution** needed to make a solution of given (target) molarity
- To calculate the molarity of a solution made by **mixing two solutions** of the same compound
- To calculate the molarity of a solution made by mixing two solutions containing a **common ion**
- To calculate the **molality** of a solution
- To calculate the quantity of a compound and solvent needed to make a solution of given (target) molality

Pre-requisites: Classes of compounds; Formulas, moles, chemical composition.

Self-study questions

Before you start studying the worked examples, you should be able to formulate answers to the questions below. Use a textbook of your choice, or an online source of information, to find the answers.

1. What is a solution? What are the components of a solution?
2. What is meant by mass percent composition?
3. What is meant by volume percent composition?
4. What is a saturated solution?
5. What is solubility?
6. What is molarity?
7. What is meant by dilution? What stays constant during dilution?
8. What is a stock solution?
9. What is molality?

Worked examples

This section contains several solved examples that cover the learning objectives listed above. Study each example carefully and make notes in the workbook to check every example that you understood. Repeat several times what you don't understand at first. It should become clearer as you keep working on the examples.

Objective 66. Calculate the mass percent composition of a solution.

1. Calculate the mass percent composition of each solution below:
   a. 23.56 g NaCl dissolved in 95.44 g H_2O
   b. 134 g $Ca(NO_3)_2$ dissolved in 125 g H_2O

Solutions

Since these compounds dissolve in water, the mass percent composition will be straightforward:

a.

$$\% \, NaCl = \frac{23.56 \ g \ NaCl}{(23.56 \ + \ 95.44) g \ solution} \times 100 = 19.80 \ \% \quad ; \quad \% \, H_2O = 80.20 \ \%$$

b.

$$\% \, Ca(NO_3)_2 = \frac{134 \ g \ Ca(NO_3)_2}{(134 + 125) g \ solution} \times 100 = 51.7 \ \% \quad ; \quad \% \, H_2O = 48.3 \ \%$$

2. What mass of $CaCl_2$ must be dissolved in water in order to make a solution that is 12.5% Ca^{2+}?

Solution

Here, instead of the percent of a full compound, we are given the mass percent of just one ion. We need 25 g Ca^{2+} in 100. g solution so let's work with these masses. We cannot obtain pure calcium ions, so we must use a compound that contains them, in this case calcium chloride (remember dissociation of salts, Objective 44). We convert the ions into the full compound with the help of moles:

$$12.5 \ g \ Ca^{2+} \times \frac{1 \ mol \ Ca^{2+}}{40.078 \ g} \times \frac{1 \ mol \ CaCl_2}{1 \ mol \ Ca^{2+}} \times \frac{110.984 \ g}{1 \ mol \ CaCl_2} = 34.62 \ g \ CaCl_2$$

Thus if we dissolve 34.62 g $CaCl_2$ in (100 – 34.62) = 65.38 g H_2O, we get a solution that contains 12.5% Ca^{2+} ions.

3. What mass of $CaCl_2$ must be added to 200.0 g H_2O in order to make a solution that is 12.5% Ca^{2+}?

Solution

Now we know that we must use 200. g water and some calcium chloride in order to make a solution that still contains 12.5% Ca^{2+} ions by mass. Again, we cannot add pure calcium ions to water, but must use calcium chloride, so let x be the mass of calcium chloride that we need.

We need to find out how much in this mass of x is just calcium ions, so we work with moles:

$$x \ g \ CaCl_2 \times \frac{1 \ mol \ CaCl_2}{110.984 \ g} \times \frac{1 \ mol \ Ca^{2+}}{1 \ mol \ CaCl_2} \times \frac{40.048 \ g}{1 \ mol \ Ca^{2+}} = 0.3611x \ g \ Ca^{2+}$$

This is the same thing as finding the mass percent composition of $CaCl_2$: it contains 36.11% Ca, so the mass of Ca^{2+} in x g of $CaCl_2$ is 0.3611 x g.

Thus, the ratio between the mass of the calcium ions ($0.3611\,x$) and the mass of the entire solution (x plus the 200. g water) must equal 12.5%:

$$\frac{0.3611x}{x + 200} = \frac{12.5}{100} = 0.125$$

So let's solve for x :

$$0.3611x = 0.125\,(x + 200) = 0.125x + 25 \;\Rightarrow 0.2361x = 25 \;\Rightarrow\; x = 105.9\ g\ CaCl_2$$

Is the result reasonable? Let's check. Since we determined that calcium chloride is 36.11% calcium ions, the mass of Ca^{2+} in the 105.9 g $CaCl_2$ is:

$$105.9\ g\ CaCl_2 \times \frac{36.11}{100} = 38.24\ g\ Ca^{2+}$$

The mass of the solution is:

$$105.9\ g\ CaCl_2 + 200.0\ g\ H_2O = 305.9\ g\ solution$$

Mass percent calcium ions:

$$\frac{38.24\ g\ Ca^{2+}}{305.9\ g\ solution} \times 100 = 12.50\ \%\ Ca^{2+}$$

Objective 67. Calculate the volume percent composition of a solution.

1. Calculate the volume percent composition of a solution made by mixing 25.0 mL water with 125.0 mL ethanol and 50.0 mL acetone
2. What volume of ethanol needs to be added to 165 mL water in order to make a solution that is 40.0% ethanol by volume?

Solutions

Volume percent composition is the same as mass percent composition but for liquids, which are more easily measured by volume.

1.

$$water = \frac{25.0\ mL}{(25.0 + 125.0 + 50.0)\ mL} \times 100 = 12.5\%\ by\ volume$$

$$ethanol = \frac{125.0\ mL}{(25.0 + 125.0 + 50.0)\ mL} \times 100 = 62.5\%\ by\ volume$$

$$acetone = \frac{50.0\ mL}{(25.0 + 125.0 + 50.0)\ mL} \times 100 = 25.0\%\ by\ volume$$

2. Let x be the volume of ethanol. Thus:

$$\frac{x}{165 + x} = \frac{40.0}{100} = 0.400 \;\Rightarrow\; x = 0.4(165 + x) = 66 + 0.4x \;\Rightarrow\; 0.6x = 66 \;\Rightarrow\; x = 110.\ mL\ ethanol$$

Is the result reasonable?

$$\frac{110.\,mL\ ethanol}{275\ mL\ mixture} \times 100 = 40.0\%$$

Objective 68. Calculate the content of a solution from mass percent composition.

Calculate the mass and mass percent of:

1. Sodium ions in 50.0 g solution that is 10.0% Na_2CO_3 by mass
2. Bromide ions in 25.4 g solution that is 2.5% $FeBr_3$ by mass

Solutions

1. We need the mass and the mass percent of sodium in this solution. We convert the mass of sodium carbonate to mass of sodium (as ions):

$$50.0\ g\ solution \times \frac{10.0\ g\ Na_2CO_3}{100\ g\ solution} = 5.00\ g\ Na_2CO_3$$

$$5.00\ g\ Na_2CO_3 \times \frac{1\ mol\ Na_2CO_3}{105.99\ g} = 0.0472\ mol\ Na_2CO_3$$

$$0.0472\ mol\ Na_2CO_3 \times \frac{2\ mol\ Na^+}{1\ mol\ Na_2CO_3} = 0.0944\ mol\ Na^+$$

$$0.0944\ mol\ Na^+ \times \frac{22.99\ g\ Na^+}{1\ mol\ Na^+} = 2.17\ g\ Na^+$$

And now the mass percent:

$$\frac{2.17\ g\ Na^+}{50.0\ g\ solution} \times 100 = 4.34\%\ Na^+$$

Does the result make sense? Yes, if the solution is 10% in sodium carbonate, then 4.34% sodium seems right.

2. Same calculation for the mass of bromine. I will do it in one long equation:

$$25.4\ g\ solution \times \frac{2.5\ g\ FeBr_3}{100\ g\ solution} \times \frac{1\ mol\ FeBr_3}{295.557\ g} \times \frac{3\ mol\ Br^-}{1\ mol\ FeBr_3} \times \frac{79.904\ g}{1\ mol\ Br^-} = 0.515\ g\ Br^-$$

$$\frac{0.515\ g\ Br^-}{25.4\ g\ solution} \times 100 = 2.03\%\ Br^-$$

Does the result make sense? Yes, the solution is 2.5% $FeBr_3$, and bromine represents most of the mass of the solute, so 2.03% seems right.

Objective 69. Calculate the composition of a saturated solution of a salt at a given temperature.

Calculate the mass percent composition of each saturated solution below. Obtain the solubility of the salt from the solubility chart provided in Appendix D.

1. KCl at 60°C
2. $NaNO_3$ at 5°C

Solutions

The chart we are referred to is called a solubility chart. It contains solubility curves, which tell us how much of a compound dissolves in exactly 100 g of water at a given temperature between 0 and 100 °C. The solubility of a salt generally increases with temperature, but a few have the opposite effect. When given a certain temperature, we determine the solubility of a given salt from the chart, by intersecting the temperature line with the solubility curve. Of course, for temperatures other than every 10°C, we would need to construct our own line.

1. KCl at 60°C.

From the chart, we estimate the solubility of KCl at 60°C to be 43 g per 100 g water (since the y scale has divisions every 10 g, we can only estimate to the nearest gram). Thus:

$$\frac{43\ g\ KCl}{(43+100)g\ solution}\times 100 = 30.1\%\ KCl, \qquad and\ thus\ 69.9\%\ H_2O$$

2. $NaNO_3$ at 5°C.

5°C does not have a line drawn on the chart, so we make one (try on paper) and we estimate the solubility as 76g $NaNO_3$ per 100 g H_2O (you may disagree if you'd like). Thus:

$$\frac{76g\ NaNO_3}{(76+100)g\ solution}\times 100 = 43.2\%\ NaNO_3, \qquad and\ 56.8\%\ H_2O$$

Objective 70. Calculate the solubility of a compound from the mass percent composition of a saturated solution.

Calculate the solubility of each compound below in water from the mass percent composition of the solution (temperature not specified).

1. A saturated solution containing 47.6% $MgSO_4$ by mass
2. A saturated solution containing 35.2% NaCl by mass.

Solutions

Here, we calculate the solubility of a salt, in grams of salt per 100 g of water, from the mass percent composition. We work backwards:

1. A saturated solution containing 47.6% $MgSO_4$ by mass

47.6% $MgSO_4$ by mass means that a saturated solution will contain 47.6 g $MgSO_4$ and 52.4 g H_2O in each 100.0 g solution. We need to set up a proportion in order to find the solubility as defined above:

$$\frac{47.6\ g\ MgSO_4}{52.4\ g\ H_2O} = \frac{x\ g\ MgSO_4}{100.0\ g\ H_2O}$$

This is true because solubility is directly proportional, so we need to find the mass of solute that will dissolve in 100 g water. Solving for x we get:

$$x = \frac{47.6\ x\ 100.0}{52.4} = 90.8\ g\ MgSO_4\ per\ 100.0\ g\ water$$

2. A saturated solution containing 35.2% NaCl by mass.

$$\frac{35.2\ g\ NaCl}{64.8\ g\ H_2O} = \frac{x\ g\ NaCl}{100.0\ g\ H_2O} \quad \Rightarrow \quad x = \frac{35.2\ \times\ 100.0}{64.8} = 54.3\ g\ NaCl\ per\ 100.0\ g\ water$$

Objective 71. Calculate the molarity of a solution when a compound is dissolved in water.

Calculate the molarity of each solution below.

1. 3.0 mol H_2SO_4 in 500. mL of solution.
2. 25.64 g $NaOH$ in 2000.0 mL of solution.
3. 3.456 g $CuSO_4 \cdot 5H_2O$ in 250.00 mL solution.

Solutions

Molarity, or molar concentration, represents the number of moles of solute per liter of solution:

$$Molarity = \frac{moles\ of\ solute}{volume\ of\ solution\ (in\ L)} \quad ; \quad M = \frac{n}{V}$$

Units for molarity are mol/L, or simply *M* (a 1.0 M solution contains 1.0 mol of solute per liter).

1. 3.0 mol H_2SO_4 in 500. mL of solution. All volumes in mL must be converted to L.

$$M = \frac{3.0\ mol}{0.500\ L\ solution} = 6.0\frac{mol}{L}\ (M)$$

2. 25.64 g $NaOH$ in 2000.0 mL of solution.

$$25.64\ g\ NaOH\ \times \frac{1\ mol\ NaOH}{40.00\ g} = 0.6410\ mol\ NaOH$$

$$M = \frac{0.6401\ mol}{2.0000\ L} = 0.3205\ M$$

3. 3.456 g $CuSO_4 \cdot 5H_2O$ in 250.00 mL solution.

$$3.456\ g\ CuSO_4 \cdot 5H_2O \quad \times \frac{1\ \text{mol CuSO}_4\ \cdot\ 5\text{H}_2\text{O}}{249.685\ \text{g}} = 0.01384\ \text{mol}\ CuSO_4 \cdot 5H_2O$$

$$M = \frac{0.01384\ \text{mol}}{0.250\ L} = 0.05537\ M$$

Do not worry about the water from the hydrate here; the volume of solution is 250 mL, which incorporates the little amount of water that comes from the hydrate.

Objective 72. Calculate the molarity of each ion in a solution.

Calculate the molar concentration of each ion in each of the following solutions:

1. 0.125 M $NaCl$
2. 0.340 M $FeBr_3$
3. 0.250 M $Al_2(SO_4)_3$

Solutions

When we are given the molar concentration of a salt, it refers to the moles of the entire salt per liter of solution. But as we know, soluble salts dissociate into ions. An important quantity is the molarity of each ion in solution, because, as we have seen in net ionic equations, it is the ions that do the work in a reaction (and we need solutions to do some work for us, not to just sit there). So, the actual concentration of ions in solution depends on how many ions are in each formula unit of a salt.

1. 0.125 M $NaCl$

$$NaCl \xrightarrow{in\ water} Na^+{}_{(aq)} + Cl^-{}_{(aq)}$$

Since there are 1 of each ion per formula unit of NaCl, the concentrations of each ion is the same as that of the entire salt. So this solution is 0.125 M in Na^+ and also 0.125 M in Cl^-.

2. 0.340 M $FeBr_3$

$$FeBr_3 \xrightarrow{in\ water} Fe^{3+}{}_{(aq)} + 3Br^-{}_{(aq)}$$

We're not going to do dimensional analysis for such simple things. The solution is 0.340 M in Fe^{3+} and 1.02 M in Br^-.

3. 0.250 M $Al_2(SO_4)_3$

Clearly, 0.500 M in Al^{3+} and 0.750 M in SO_4^{2-}.

Objective 73. Calculate the quantity of solute in a given volume of solution of known concentration.

Calculate the following:

1. How many moles and *m*moles of $MgCl_2$ are found in 60.0 mL of 0.100 M solution?
2. How many grams of KOH are found in 35.0 mL of 2.50 M solution?
3. How many grams of Fe^{2+} are found in 75.0 mL of 0.250 M solution of $FeSO_4$?

Solutions

1. How many moles of $MgCl_2$ is found in 60.0 mL of 0.100 M solution?

$$M = \frac{n}{V} \quad \Rightarrow \quad n = MV = 0.100\frac{mol}{L} \times 60.0\ mL \times \frac{1\ L}{1000\ mL} = 6.00 \times 10^{-3}\ mol = 6.00\ mmol\ MgCl_2$$

Yes, get used to working in mmol, as they will be the more convenient unit for most calculations. If we use mmol, then we don't need to convert mL to L anymore, as you'll see.

2. How many grams of KOH are found in 35.0 mL of 2.50 M solution?

$$n = MV = 2.50\frac{mol}{L} \times 35.0\ mL = 87.5\ mmol\ KOH$$

$$87.5\ mmol\ KOH \times \frac{1\ mol}{1000\ mmol} \times \frac{56.106\ g}{1\ mol\ KOH} = 4.91\ g\ KOH$$

3. How many grams of Fe^{2+} are found in 75.0 mL of 0.250 M solution of $FeSO_4$?

$$n = 0.250\frac{mol}{L} \times 75.0\ mL = 18.75\ mmol\ FeSO_4$$

$$18.75\ mmol\ FeSO_4 \times \frac{1\ mol}{1000\ mmol} \times \frac{1\ mol\ Fe^{2+}}{1\ mol\ FeSO_4} \times \frac{55.845\ g\ Fe^{2+}}{1\ mol\ Fe^{2+}} = 1.05\ g\ Fe^{2+}$$

Objective 74. Calculate the quantity of a compound needed to make a solution of given (target) molarity.

Calculate the mass of compound needed to make each solution below and describe how the solution should be made.

1. 250.0 mL of 0.757M $NaNO_3$
2. The mass of $CuSO_4 \cdot 5H_2O$ needed to make 125 mL solution of 0.200 M Cu^{2+} ?

Solutions

To make a solution of anything from a solid, we need to weigh the compound and dissolve in pure water, adjusting the volume to the required quantity. This is done typically in volumetric flasks. In order to find the mass of compound needed, we calculate the moles and convert to mass.

1. 250.0 mL of 0.757M $NaNO_3$

$$n = MV = 0.757\frac{mol}{L} \times 250.0\ mL = 189.25\ mmol\ NaNO_3$$

$$189.25\ mmol\ NaNO_3 \times \frac{1\ mol}{1000\ mmol} \times \frac{84.995\ g}{1\ mol\ NaNO_3} = 16.085\ g\ NaNO_3$$

So, we dissolve 16.1 g $NaNO_3$ in water, adjust the total solution volume to 250.0 mL in a volumetric flask, and we have the solution requested.

2. The mass of $CuSO_4 \cdot 5H_2O$ needed to make 125 mL solution of 0.200 M Cu^{2+} ?

$$n = MV = 0.200\frac{mol}{L} \times 125\ mL = 25.0\ mmol\ Cu^{2+}$$

$$25.0\ mmol\ Cu^{2+} \times \frac{1\ mol}{1000\ mmol} \times \frac{1\ mol\ CuSO_4 \cdot 5H_2O}{1\ mol\ Cu^{2+}} \times \frac{249.685\ g}{1\ mol\ CuSO_4 \cdot 5H_2O} = 6.24\ g\ CuSO_4 \cdot 5H_2O$$

We weigh 6.24 $g\ CuSO_4 \cdot 5H_2O$ on a balance, dissolve in water, adjust to 125 mL in a volumetric flask, and we have a solution that is 0.200 M in Cu^{2+}.

Objective 75. Calculate the molarity of a solution after dilution.

Each solution below is diluted. Calculate the new molarity in each case.

1. 10.00 mL of 2.00 M $NaOH$ is diluted to 500.0 mL total.
2. 12.55 mL water is added to 2.45 mL of 6.00 M H_2SO_4.

Solutions

When a solution is diluted, we add water to it to increase its volume, and thus make it less concentrated (more diluted). What does not change in this process is the number of moles of solute, as we only add solvent. So if we denote (1) as the quantities before dilution, and (2) the quantities after dilution, we can write:

$$n = M_1V_1 = M_2V_2$$

This is called the dilution formula and it is very convenient to use in problems. Given three quantities, we solve for the fourth, whatever that maybe.

1. 10.00 mL of 2.00 M $NaOH$ is diluted to 500.0 mL total.

We know the volume and the molarity before dilution, as well as the volume after dilution. We solve for M_2, right?

$$M_1V_1 = M_2V_2 \Rightarrow M_2 = \frac{M_1V_1}{V_2} = \frac{2.00\ M \times 10.00\ mL}{500.0\ mL} = 0.0400\ M$$

Since volumes cancel out we do not need any conversion in liters, and we get molar units as the final answer.

2. 12.55 mL water is added to 2.45 mL of 0.7500 M H_2SO_4.

We know the initial volume and molarity, and we know how much solvent (water) is added.

$$M_1V_1 = M_2V_2 \ \Rightarrow \ M_2 = \frac{M_1V_1}{V_2} = \frac{0.750\ M \times 2.45\ mL}{(2.45 + 12.55)\ mL} = \frac{0.750\ M \times 2.45\ mL}{15.00\ mL} = 0.123\ M$$

Objective 76. Calculate the volume or molarity of stock solution needed to make a solution of given (target) molarity.

In each case below, a solution of a certain concentration needs to be prepared from a more concentrated (stock) solution available. Calculate the volume of stock solution or the molarity of the stock solution as needed.

1. 250.00 mL of 0.122 M HCl made from 11.5 M stock HCl
2. 500.00 mL of 0.400 M NaOH made by diluting 20.9 mL stock NaOH

Solutions

1. 250.00 mL of 0.122 M HCl made from 11.5 M HCl

$$M_1V_1 = M_2V_2 \ \Rightarrow \ V_1 = \frac{M_2V_2}{M_1} = \frac{0.122\ M \times 250.00\ mL}{11.5\ M} = 2.65\ mL\ stock\ solution$$

2. 500.00 mL of 0.400 M NaOH made from 9.54 M NaOH

$$M_1V_1 = M_2V_2 \ \Rightarrow \ M_1 = \frac{M_2V_2}{V_1} = \frac{0.400\ M \times 500.00\ mL}{20.9\ mL} = 9.57\ M$$

Objective 77. Calculate the molarity of a solution made by mixing two solutions of the same compound.

In each case below, two solutions of the same compound, but of different concentrations, are mixed. Calculate the concentration of the resulting solution.

1. 25.0 mL of 0.125 M HCl and 75.0 mL of 0.334 M HCl
2. 200. mL of 0.200 M $CuSO_4$ and 200. mL of 0.400 M $CuSO_4$

Solutions

When two solutions of the same compound are mixed, the volumes add up, and the moles of solute from the two solutions also add up. So the final concentration would be:

$$Final\ molarity = \frac{total\ moles\ of\ solute}{total\ volume\ of\ solution}$$

1. 25.0 mL of 0.125 M HCl and 75.0 mL of 0.334 M HCl

$$M = \frac{n_1 + n_2}{V_1 + V_2} = \frac{M_1V_1 + M_2V_2}{V_1 + V_2} = \frac{0.125\ M \times 25.0\ mL + 0.334\ M \times 75.0\ mL}{25.0\ mL + 75.0\ mL} = 0.28175 = 0.282\ M$$

Does the answer make sense? Yes, the resulting molarity should be between those of the solutions mixed, and it should be closer to that of the solution taken in a larger amount.

2. 200. mL of 0.200 M $CuSO_4$ and 200. mL of 0.400 M $CuSO_4$

Do we need to calculate this one? I am going to say that the final concentration will be 0.300 M. Figure out why!

Objective 78. Calculate the molarity of a solution made by mixing two solutions containing a common ion.

In the case below, two solutions of different compounds containing a common ion are mixed. Calculate the concentration of each ion in the resulting solution.

75.4 mL of 0.228 M HNO_3 and 46.8 mL of 0.148 M $Ca(NO_3)_2$

Solution

Here, we mix solution of different compounds, which have a common ion. First we need to make sure that the solutes do not react with each other once mixed, as that would be a different story. Then, we calculate the concentration of each ion separately, and after that we look at the dilution. When the solutions are mixed, everything inside occupies the entire new volume.

First solution: 0.228 M HNO_3 will be 0.228 M in H^+ and 0.228 M in NO_3^- (Objective 72).

Similarly, second solution: 0.148 M in $Ca(NO_3)_2$ will be 0.148 M in Ca^{2+} and 0.296 M in NO_3^-.

The common ion is nitrate. This means that when the solutions are mixed, the moles of nitrate from both sources need to be added up and divided by the new volume (Objective 77). The other ions, hydrogen and calcium, come only from one source, and so they are only subject to a dilution (Objective 75). Here are the calculations:

$$M_{NO_3^-} = \frac{M_1V_1 + M_2V_2}{V_1 + V_2} = \frac{0.228\ M \times 75.4\ mL + 0.296\ M \times 46.8\ mL}{75.4\ mL + 46.8\ mL} = 0.254\ M\ NO_3^-$$

H^+ comes only from solution 1:

$$M_{H^+} = \frac{M_1V_1}{V_1 + V_2} = \frac{0.228\ M \times 75.4\ mL}{75.4\ mL + 46.8\ mL} = 0.141\ M\ H^+$$

Ca^{2+} comes only from solution 2:

$$M_{Ca^{2+}} = \frac{M_2V_2}{V_1 + V_2} = \frac{0.148\ M \times 46.8\ mL}{75.4\ mL + 46.8\ mL} = 0.0566\ M\ Ca^{2+}$$

Do these answers make sense?

Objective 79. Calculate the molality of a solution.

Calculate the molality of each solution prepared as described below.

1. 23.56 g NaCl dissolved in 124.81 g H_2O.
2. 26.458 g $CuSO_4 \cdot 5H_2O$ dissolved in 200.00 g H_2O

Solutions

Molality is another way of expressing concentration:

$$molality\ (m) = \frac{number\ of\ moles\ of\ solute}{mass\ of\ solvent\ (in\ kg)}$$

Units for molality are mol/kg (implying solvent), or simply *m*. There are two crucial differences between molarity and molality: the denominator of the fraction for molality has <u>mass</u>, not volume, and it refers to <u>solvent</u>, not solution. Also, the units must be **kg**! Molarity can be converted into molality if the density of the solution is known. This will be learned later in this course.

1. 23.56 g NaCl dissolved in 124.81 g H_2O.

$$\frac{23.56\ g\ NaCl}{58.44\ g/mol} = 0.4031\ mol\ NaCl$$

$$m = \frac{0.4031\ mol}{0.12481\ kg\ water} = 3.230\ m$$

2. 26.458 g $CuSO_4 \cdot 5H_2O$ dissolved in 200.00 g H_2O

Here, a hydrate is dissolved in water, and the water from the hydrate will mix with the water solvent, and needs to be added as such. Thus, we need to figure out the mass of water in the given mass of hydrate (Objective 59).

$$\frac{26.458\ \mathrm{g\ CuSO_4 \cdot 5H_2O}}{249.685\ \mathrm{g/mol}} = 0.10196\ mol\ \mathrm{CuSO_4 \cdot 5H_2O} = 0.10196\ \mathrm{mol\ CuSO_4\ and\ 0.50980\ mol\ H_2O}$$

$$0.50980\ \mathrm{mol\ H_2O} \times 18.015\frac{\mathrm{g}}{\mathrm{mol}} = 9.1840\ \mathrm{g\ H_2O}$$

Total mass of water: $200.00\ g + 9.1840\ g = 209.18\ g = 0.20918\ kg\ water\ (solvent)$

$$m = \frac{0.10196\ \mathrm{mol\ CuSO_4}}{0.20918\ kg\ water} = 0.48743\ m \quad (5\ sig\ figs\ neded)$$

Objective 80. Calculate the quantity of a compound and solvent needed to make a solution of given (target) molality.

1. Calculate the mass of compound and that of solvent needed to make 256.00 g of 0.500 m $CaCl_2$

Solution

Here we know the total mass of the target solution (256 g) and its molality, 0.500 m.

$$m = \frac{moles\ of\ CaCl_2}{mass\ of\ water\ (kg)}$$

Let x be the moles of the $CaCl_2$ we need. The mass of $CaCl_2$ will be:

$$x\ moles\ CaCl_2 \times 110.98 \frac{g}{mol} = 110.98x \quad (in\ g)$$

The mass of the water will be the mass of the solution minus the mass of the calcium chloride:

$$mass\ of\ water\ \ (kg) = \frac{256g\ solution - 110.98x\ g\ CaCl_2}{1000\ g/kg}$$

We plug these values into the molality equation and solve for x:

$$m = \frac{x}{\frac{256 - 110.98\,x}{1000}} = \frac{1000x}{256 - 110.98\,x} = 0.500$$

$$1000x = 0.5(256 - 110.98\,x) = 128 - 55.49x$$

$$1055.49\,x = 128 \quad \Rightarrow \quad x = 0.1213\ moles\ CaCl_2$$

$$0.1213\ moles\ CaCl_2 \times 110.98 \frac{g}{mol} = 13.46\ g\ CaCl_2$$

$$m_{H_2O} = 256.00 - 13.46 = 242.54\ g\ H_2O$$

Result check:

$$m = \frac{0.1213\ mol}{0.24254\ kg\ H_2O} = 0.500$$

Worksheet 10. Solutions and Concentration

The exercises and problems in this section will allow you to practice the topic until you understand it well.

1. Calculate the mass percent composition of a solution made by dissolving 13.26 g ferrous sulfate dissolved in 156.34 g water.

2. What mass of silver nitrate must be dissolved in 80.0 g water in order to make a solution that is 9.5% Ag^{+} by mass?

3. What mass of aluminum sulfate must be added to 135g water in order to make a solution that is 16.5% sulfate ions by mass?

4. A solution is 5.0% water and 95.0% ethanol by volume. What volume of water must be added in order to reduce the percent of ethanol to 25.0%?

5. Calculate the mass percent of aluminum in 455.5 g of solution that contains 11.5% aluminum sulfate by mass.

6. Calculate the mass of nitrate ions in 150.0 g solution that contains 5.00% calcium nitrate by mass.

7. Calculate the mass percent composition of each saturated solution below. Obtain the solubility of the salt from the chart provided.
   a. KNO_3 at 50 °C
   b. $MgBr_2$ at 20°C
   c. NH_4Cl at 85°C

8. Calculate the solubility of aluminum sulfate in a saturated solution that is 11.5% aluminum sulfate by mass.

9. Calculate the molarity of a solution of 22.6 g of sucrose ($C_{12}H_{22}O_{11}$) in 100.0 mL solution.

10. Calculate the molarity of a solution of 1.225 g $FeSO_4 \cdot 6H_2O$ in 50.0 mL solution.

11. Calculate the molar concentration of each ion in each of the following solutions:
    a. 0.205 M HNO_3
    b. 0.110 M sodium carbonate
    c. 0.450 M magnesium phosphate

12. Calculate the moles and mass of sodium ions in 250.00 mL of 0.336 M sodium sulfate.

13. What mass of $NaNO_3$ would be required to prepare 250.0 mL of a 0.547 *M* solution?

14. What mass of ferrous sulfate heptahydrate is needed to make 2.00 L of 0.0750 M solution?

15. Water is added to 25.0 mL of a 0.476 M solution of potassium nitrate until the volume is exactly 500.0 mL. What is the concentration of the final solution?

16. You have 55.0 mL of a 0.825 M hydrochloric acid solution and you want to dilute it to exactly 0.100 M. What is the volume of the resulting solution? How much water should you add?

17. 55.2 mL of 0.412 M solution of potassium permanganate is mixed with 63.5 mL of 0.182 M potassium permanganate. Calculate the concentration of the final solution.

18. 66.2 mL of 0.238 M solution of calcium nitrate is mixed with 50.5 mL of 0.405 M calcium nitrate. Calculate the concentrations of calcium ions and nitrate ions in the final solution.

19. 16.5 g of solid magnesium chloride is dissolved in 450. mL of 0.456 M hydrochloric acid. Calculate the concentration of chloride ions in the final solution, assuming no change in volume.

20. Calculate the molality of a solution made by dissolving 114.5 g calcium nitrate in 325.0 g water.

21. Calculate the molality of a solution made by dissolving 12.45 g magnesium sulfate heptahydrate in 85.00 g water.

22. Calculate the masses of sucrose ($C_{12}H_{22}O_{11}$) and water necessary to make 750.0 g of 1.45 m solution.

Self-assessment

Using the scale indicated, rate your understanding of each learning objective at the completion of this lesson. Identify the areas where your understanding is weak or medium and discuss with your class mates and/or instructor. Write down specific questions you still have at the completion of this topic.

Learning objective	***Self-assessment 3 = strong, 2 = medium, 1 = weak, 0 = not done***
	3 2 1 0
	3 2 1 0
	3 2 1 0
	3 2 1 0
	3 2 1 0
	3 2 1 0
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	3 2 1 0
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	3 2 1 0