Chapter 14

Solutions

Introduction

It is important to know how much solid is dissolved in a liquid. Telling someone that you added a little sugar to their iced tea does not give them much of a clue about how sweet the tea will be. A little sugar to you might mean a lot of sugar to someone else. In this chapter you will learn ways to express concentration so that you know just how much dissolved solid is present in a given volume of liquid.

Chapter Discussion

Many common ionic and nonionic substances dissolve in water. When an ionic substance dissolves, it breaks apart into ions. For example, when potassium sulfate, K_2SO_4, dissolves, it forms K^+ and SO_4^{2-} ions. To understand why a crystal of potassium sulfate breaks apart into ions, we need to consider the nature of the water molecule. Water molecules are polar; that is, one end of the molecule has a partial positive charge, and the other end has a partial negative charge. The positive potassium ion is attracted to the partial negative charge on the water molecule, and the negative sulfate ion is attracted to the partial positive charge on the water molecule. The K_2SO_4 crystal is pulled apart by the polarity of the water molecule. Ions in solution are surrounded by oppositely charged ends of water molecules.

Nonionic compounds such as ethyl alcohol, C_2H_5OH, also dissolve in water. The O–H of ethyl alcohol is polar, just as the O–H on the water molecule is. This means that alcohol molecules have a negative end and a positive end just as water molecules do. Alcohol molecules are attracted by water molecules and are dissolved in them.

Molecules which are not water soluble do not have positive or negative ends to be attracted to water.

One way of describing the composition of a solution is mass percent. The mass percent of a solution is the mass of solute dissolved by the total mass of the solute plus solvent, multiplied by 100%.

$$\text{mass percent} = \left(\frac{\text{mass of solute}}{\text{mass of solution}}\right) \times 100\%$$

However, the mass percent of a solution is inconvenient to use when the solvent is liquid. It is much more convenient to measure the volume of a liquid than it is to measure its mass. The most often used indication of the amount of solute in a given volume of solution is molarity. Molarity is equal to the number of moles of solute per volume of solution.

$$\text{Molarity} = \left(\frac{\text{moles of solute}}{\text{liters of solution}}\right)$$

This is often abbreviated as M = mol/L.

When the molarity of a solution is calculated, it is assumed that the solute is in the form it would be in before it dissolved. One mole of Na_2SO_4 when added to water produces two moles of Na^+ ions and one mole of SO_4^{2-} ions.

$$1.0 \text{ mol } Na_2SO_4 \rightarrow 2.0 \text{ mol } Na^+ + 1.0 \text{ mol } SO_4^{2-}$$

Compounds that do not form ions have the same molar concentration before and after they dissolve in water. Sucrose, table sugar, dissolves in water but does not form ions. 1 mol of sucrose in 1 liter of solution produces a 1 M solution of sucrose.

Dilution is the process of adding more solvent to a solution. When we prepare a dilute solution, we are measuring a quality of a stock solution (relatively highly concentrated solution) and adding it to water. The amount of solute in the measured portion of stock solution is the same as the amount of solute in the more dilute solution. The only thing which has changed is the volume of the solution. We have decreased the concentration of the solution by increasing the volume, but the amount of solute stays the same.

In Chapter 9, you learned to solve stoichiometry problems. From the balanced equation you could answer questions about the quantity of reactant required or the quantity of product produced. The same principles are used here, but the reactions occur in solution. In Chapter 9 we used molar mass to convert mass to moles. Here, we use molarity to convert volume of solution to moles. Use the steps in Section 14.6 of your text.

Learning Review

1. 150 mL of ethyl alcohol is mixed with 1 L of water. Which is the solute, ethyl alcohol or water?

2. Which of the molecules below would you predict to be soluble in water?

   a. CH_2O-OH
      |
      CH_2O-OH
      |
      CH_2O-OH

   b. $CH_3CH_2CH_3$

   c. K_2SO_4

3. Three solutions are prepared by mixing the quantities of sodium chloride given below in a volume of 500 mL of solution. Which solution is the most concentrated?

   a. 55 g NaCl in 500 mL solution
   b. 127 g NaCl in 500 mL solution
   c. 105 g NaCl in 500 mL solution

4. A student stirred 5.0 g of table sugar into 250. g of hot coffee. What is the mass percent of sugar in the coffee?

5. Calculate mass percents for the solutions below.

   a. 6.5 g KOH in 250. g water
   b. 0.40 g baking soda in 2000.0 g flour
   c. 150. g acetone in 438 g water

6. A solution of HCl in water is 0.15 M. How many mol/L of HCl are present?

7. 150.5 g of NaOH are dissolved in water. The final volume of the solution is 3.8 L. What is the molarity of the solution?

8. Calculate the molarity of each of the solutions below.

   a. 0.62 g $AgNO_3$ in a final volume of 1.5 L solution
   b. 10.6 g NaCl in a final volume of 286 mL solution
   c. 152 g $Ca(NO_3)_2$ in a final volume of 0.92 L solution

9. 2.5 L of a solution of KI in water has a concentration of 0.15 M. How many grams of KI are in the solution?

10. What is the concentration of each ion in the following solutions?

    a. 2.0 M H_2SO_4
    b. 0.6 M Na_3PO_4
    c. 1.5 M $AlCl_3$

11. How many moles of KCl are present in 1.5 L of a 0.48 M solution of KCl in water?

12. How many grams of NaOH are needed to make 1.50 L of a 0.650 M NaOH solution?

13. How many grams of K_2SO_4 are needed to make 250 mL of a 0.150 M K_2SO_4 solution?

14. Sodium fluoride is added to many water supplies to prevent tooth decay. How many grams of NaF must be added to a water supply so that 2.0×10^6 L of water contain 3.0×10^{-6} M NaF?

15. What volume of 12 M HCl solution is needed to make 2.5 L of 1.0 M HCl?

16. What volume of 18 M H_2SO_4 stock solution is needed to make 1855 mL of 0.65 M H_2SO_4?

17. If 2.5 L of solution contains 0.10 M $CaCl_2$, how many grams of Na_3PO_4 are needed to exactly precipitate all of the calcium as $Ca_3(PO_4)_2$?

18. How many grams of $Fe(OH)_3$ can be produced by the addition of 0.25 moles of $FeCl_3$ to 1.2 L of a 0.85 M NaOH solution?

19. What volume of 0.15 M NaOH solution will react completely with 150 mL of 0.25 M HCl?

20. For each of the strong acids and strong bases below, give the number of equivalents present in 1 mole, and the equivalent weight of each.

Material	molar mass	equivalents	equivalent weight
1.0 mol HCl	36.46		
1.0 mol H_2SO_4	98.08		
1.0 mol KOH	56.11		

21. If 5.6 grams of phosphoric acid, H_3PO_4, are added to water so that the final volume is 125 mL, what is the normality of the solution?

Answers to Learning Review

1. Ethyl alcohol is the solute. Water is the solvent, because it is present in the largest amount.

2. a. This molecule contains three polar O-H bonds. Each of these O-H bonds can form hydrogen bonds with water. This molecule is soluble in water.
   b. This molecule has no polar bonds. There is no part of the molecule which will interact with polar water molecules. This molecule is not soluble in water.
   c. Potassium sulfate is an ionic compound. Many ionic compounds dissolve in water because the charged ions are pulled from the crystal by the polar water molecules. This molecule is soluble in water.

3. Solution b, 127 g NaCl per 500 mL solution, is the most concentrated because the amount of solute per amount of solution is the greatest.

4. The mass percent of a solution can be calculated by

$$\text{mass percent} = \left(\frac{\text{mass of solute}}{\text{mass of solution}}\right) \times 100\%$$

The mass of solute is 5.0 g sugar; and the mass of the solution is the mass of solute plus the mass of the solvent, 5.0 g sugar plus 250. g coffee equals 255 g solution. The mass percent sugar is

$$\frac{5.0\ \cancel{g}\ \text{sugar}}{255\ \cancel{g}\ \text{solution}} \times 100\% = 2.0\%\ \text{sugar}$$

5. a. The mass of solute is 6.5 g KOH and the mass of solution is 6.5 g KOH plus 250. g water, which is 257 g. The mass percent is

$$\frac{\text{mass of solute}}{\text{mass of solution}} = \frac{6.5\ \cancel{g}\ \text{KOH}}{257\cancel{g}\ \text{solution}} \times 100\% = 2.5\%\ \text{KOH}$$

   b. The mass of solute is 0.40 g and the mass of solution is 0.40 g baking soda plus 2000.0 g flour, which is equal to 2000.4 g. The mass percent is

$$\frac{0.40\ \cancel{g}\ \text{baking soda}}{2000.4\ \cancel{g}\ \text{solution}} \times 100\% = 0.02\%\ \text{baking soda}$$

c. The mass of solute is 150. g acetone and the mass of solution is 150. g of acetone plus 438 g water, which is 588 g. The mass percent is:

$$\frac{150.\ \not{g}\ \text{acetone}}{588\ \not{g}\ \text{solution}} \times 100\% = 25.5\%\ \text{acetone}$$

6. The definition of molarity, M, is moles solute/liter solution. An HCl solution which is 0.15 M would contain 0.15 mol HC1/liter solution.

$$0.15\ \text{M HCl} = \frac{0.15\ \text{mol HCl}}{\text{L}}$$

7. The molarity of a solution is equal to the moles solute/liter solution. In this problem we have 150.5 g solute, NaOH. We do not know the number of moles. Using the molar mass for NaOH, we can calculate the number of moles.

$$150.5\ \not{g}\ \text{Na}\not{O}\text{H} \times \frac{1\ \text{mol NaOH}}{40.00\ \not{g}\ \text{Na}\not{O}\text{H}} = 3.763\ \text{mol NaOH}$$

Now, we can find the molarity.

$$\text{M} = \frac{\text{moles solute}}{\text{liter solution}}$$

$$\text{M} = \frac{3.763\ \text{mol NaOH}}{3.8\ \text{L}}$$

$$\text{M} = 0.99\ \text{M NaOH}$$

8. a. First, calculate the moles of $AgNO_3$.

$$0.62\ \not{g}\ \text{Ag}\not{N}\text{O}_3 \times \frac{1\ \text{mol AgNO}_3}{169.91\ \not{g}\ \text{Ag}\not{N}\text{O}_3} = 0.0036\ \text{mol AgNO}_3$$

Now, calculate the molarity.

$$\text{M} = \frac{0.0036\ \text{mol AgNO}_3}{1.5\ \text{L}}$$

$$\text{M} = 2.4 \times 10^{-3}\ \text{M AgNO}_3$$

b. First, calculate the moles of NaCl.

$$10.6\ \not{g}\ \text{N}\not{a}\text{Cl} \times \frac{1\ \text{mol NaCl}}{58.44\ \not{g}\ \text{N}\not{a}\text{Cl}} = 0.181\ \text{mol NaCl}$$

The volume of the solution is given in milliliters. We need to know the number of liters.

$$286\ \not{m}\text{L solution} \times \frac{1\ \text{L solution}}{1000\ \not{m}\text{L solution}} = 0.286\ \text{L solution}$$

Now, calculate the molarity.

$$\text{M} = \frac{0.181\ \text{mol NaCl}}{0.286\ \text{L solution}}$$

$$\text{M} = 0.633\ \text{M NaCl}$$

c. First, calculate the moles of $Ca(NO_3)_2$

$$152 \text{ g } Ca(NO_3)_2 \times \frac{1 \text{ mol } Ca(NO_3)_2}{164.10 \text{ g } Ca(NO_3)_2} = 0.926 \text{ mol } Ca(NO_3)_2$$

Now, calculate the molarity.

$$M = \frac{0.926 \text{ mol } Ca(NO_3)_2}{0.92 \text{ L solution}}$$

$$M = 1.0 \text{ M } Ca(NO_3)_2$$

9. This problem gives us the number of liters of solution and the molar concentration of the solution. From the definition of molarity, moles solute/liter solution, we can calculate the number of moles of solute, KI.

$$2.5 \text{ L solution} \times \frac{0.15 \text{ mol KI}}{\text{L solution}} = 0.38 \text{ mol KI}$$

Now use the molar mass of KI to calculate the grams of KI.

$$0.38 \text{ mol KI} \times \frac{166.0 \text{ g KI}}{\text{mol KI}} = 63 \text{ g KI}$$

10. a. Sulfuric acid produces 2 moles of hydrogen ions and 1 mole of sulfate ions for each mole of sulfuric acid.

$$1 \text{ mol } H_2SO_4(aq) \rightarrow 2 \text{ mol } H^+(aq) + 1 \text{ mol } SO_4^{2-}(aq)$$

A 2.0 M solution of sulfuric acid would contain 2(2.0 mol H^+) per liter, or 4.0 M H^+ total, and 2(1.0 mol SO_4^{2-}) per liter, or 2.0 M SO_4^{2-}.

b. Sodium phosphate produces 3 moles of sodium ions for each mole of sodium phosphate, and 1 mole of phosphate ions for each mole of sodium phosphate.

$$1 \text{ mol } Na_3PO_4(aq) \rightarrow 3 \text{ mol } Na^+(aq) + 1 \text{ mol } PO_4^{3-}(aq)$$

A 0.6 M solution of sodium phosphate would contain 3(0.6 mol Na^+) per liter, or 1.8 M Na^+, and 1(0.6 mol PO_4^{3-}) per liter, or 0.6 M PO_4^{3-}.

c. Aluminum chloride produces 1 mole of aluminum ions for each mole of aluminum chloride, and 3 moles of chloride ions for each mole of aluminum chloride.

$$1 \text{ mol } AlCl_3(aq) \rightarrow 1 \text{ mol } Al^{3+}(aq) + 3 \text{ mol } Cl^-(aq)$$

A 1.5 M solution of aluminum chloride would contain 1(1.5 mol Al^{3+}) per liter, or 1.5 M Al^{3+}, and 3(1.5 mol Cl^-) per liter, or 4.5 M Cl^-.

11. We are given the concentration and the volume of a solution containing KCl and water, and are asked for the number of moles of solute, KCl. The number of moles of KCl can be calculated from the definition of molarity, moles solute/liter solution.

$$1.5 \text{ L solution} \times \frac{0.48 \text{ mol KCl}}{\text{L solution}} = 0.72 \text{ mol KCl}$$

12. We are given the concentration of a solution containing NaOH and water and we are asked for the number of grams of NaOH needed to make 1.50 L of solution. The number of moles of NaOH can be calculated from the definition of molarity, moles solute per liter of solution. The grams of NaOH can be calculated using the molar mass of NaOH.

$$1.50 \text{ L solution} \times \frac{0.650 \text{ mol NaOH}}{\text{L solution}} \times \frac{40.00 \text{ g NaOH}}{\text{mol NaOH}} = 39.0 \text{ g NaOH}$$

13. We are given the concentration of a solution containing K_2SO_4 and water, and we are asked for the number of grams of K_2SO_4 needed to make 250 mL of solution. The number of moles of K_2SO_4 can be calculated from the definition of molarity. The grams of K_2SO_4 can be calculated using the molar mass of K_2SO_4. We will need to convert the given units of volume, milliliters, to liters.

$$250 \text{ mL solution} \times \frac{1 \text{ L solution}}{1000 \text{ mL solution}} \times \frac{0.150 \text{ mol } K_2SO_4}{\text{L solution}} \times \frac{174.27 \text{ g } K_2SO_4}{\text{mol } K_2SO_4} = 6.5 \text{ g } K_2SO_4$$

14. We are given the concentration of a solution containing NaF and water, and we are asked for the number of grams of NaF needed to make 2.0×10^6 L of solution. The number of moles of NaF can be calculated from the definition of molarity. The grams of NaF can be calculated from the molar mass of NaF.

$$2.0 \times 10^6 \text{ L solution} \times \frac{3.0 \times 10^{-6} \text{ mol NaF}}{\text{L solution}} \times \frac{41.99 \text{ g NaF}}{\text{mol NaF}} = 2.5 \times 10^2 \text{ g NaF}$$

15. In this problem we are asked to calculate how much of a concentrated stock solution, which is 12 M HCl, is needed to prepare a dilute HCl solution. We will need to know how many moles of HCl are present in 2.5 L of 1.0 M HCl, that is, in the dilute solution. Then we need to find a volume of the concentrated solution which contains this same number of moles. We can use this procedure because the number of moles of solute in the dilute solution is the same as the number of moles of solute in the volume of stock solution. Only the volume of water changes. First, find the number of moles of HCl which will be present in the dilute solution by multiplying the volume by the molarity.

$$2.5 \text{ L solution} \times \frac{1.0 \text{ mol HCl}}{\text{L solution}} = 2.5 \text{ mol HCl}$$

So the dilute solution will contain 2.5 mol HCl, and the volume of stock solution we need will also contain 2.5 mol HCl. The volume of stock solution multiplied by the molarity of the stock solution equals the number of moles of HCl which will be in the dilute solution.

$$\text{volume of stock solution} \times \frac{\text{mol HCl in stock solution}}{\text{L stock solution}} = \text{mol HCl in dilute solution}$$

Now, substitute values into the equation.

$$V \times \frac{12 \text{ mol HCl}}{\text{L solution}} = 2.5 \text{ mol HCl}$$

Rearrange the equation to isolate V on one side.

$$V = \frac{2.5 \text{ mol HCl}}{12 \text{ mol HCl/L solution}}$$

$$V = 0.21 \text{ L HCl}$$

So to make 2.5 L of 1.0 M HCl, use 0.21 L of 12 M HCl, and add enough water to bring the total volume to 2.5 L.

A different way to approach this problem is to use the formula

$$M_1 \times V_1 = M_2 \times V_2$$

M_1 represents the molarity of the stock solution; V_1, the volume of the stock solution needed; M_2, the molarity of the dilute solution we wish to make; and V_2, the volume of the dilute solution. In this case we want to know the volume of stock solution needed, so isolate V_1 on one side of the equation by dividing both sides by M_1.

$$M_1 \times V_1 = M_2 \times V_2$$

$$\frac{M_1}{M_1} \times V_1 = V_2 \times \frac{M_2}{M_1}$$

$$V_1 = V_2 \times \frac{M_2}{M_1}$$

Now, substitute values into the equation.

$$V_1 = 2.5 \text{ L} \times \frac{1.0 \text{ M}}{12 \text{ M}}$$

$$V_1 = 0.21 \text{ L}$$

The answer to this problem is the same, either way we solve it.

16. We want to know how much concentrated stock solution is needed to make 1855 mL of 0.65 M H_2SO_4. We can use the formula

$$M_1 \times V_1 = M_2 \times V_2$$

M_1 is the molarity of the stock solution, V_1 is the volume of the stock solution, M_2 is the molarity of the dilute solution, and V_2 is the volume of the dilute solution. We want to know how much stock solution is needed, so isolate V_1 on one side of the equation.

$$V_1 = V_2 \times \frac{M_2}{M_1}$$

The volume of the dilute solution, V_2, is given in milliliters. We will need to convert milliliters to liters.

$$1855 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 1.855 \text{ L}$$

Now, substitute values into the equation.

$$V_1 = 1.855 \text{ L} \times \frac{0.65 \text{ M } H_2SO_4}{18 \text{ M } H_2SO_4}$$

$$V_1 = 0.067 \text{ L}$$

So, 0.067 L of 18 M H_2SO_4 diluted to 1.855 L would produce a 0.65 M H_2SO_4 solution.

17. In this problem a solution of $CaCl_2$ is mixed with a solution of Na_3PO_4. A reaction occurs. We are asked for the number of grams of Na_3PO_4 which will react with the $CaCl_2$. Section 14.6 of your textbook gives 5 steps for solving problems like this one, so let's follow those same steps here.

Step 1: First, write the balanced molecular equation for this reaction. Because this is a reaction between ionic compounds, we also should write the net ionic equation. The balanced molecular equation is

$$3CaCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + 6NaCl(aq)$$

The net ionic equation is the solid product, $Ca_3(PO_4)_2$, and the ions which react to form the solid product.

$$3Ca^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Ca_3(PO_4)_2(s)$$

Step 2: We need to add just enough PO_4^{3-} to react with all the Ca^{2+}. We need to know how many moles of Ca^{2+} there are in the $CaCl_2$ solution. From the volume and the molarity of the $CaCl_2$ solution, we can calculate the number of moles of Ca^{2+}.

$$V \times M = \text{mol } CaCl_2$$

$$2.5 \text{ L } CaCl_2 \times \frac{0.1 \text{ mol } CaCl_2}{\text{L } CaCl_2} = 0.25 \text{ mol } CaCl_2$$

Each mole of $CaCl_2$ produces 1 mole of Ca^{2+}.

$$0.25 \text{ mol } CaCl_2 \times \frac{1 \text{ mol } Ca^{2+}}{1 \text{ mol } CaCl_2} = 0.25 \text{ mol } Ca^{2+}$$

Step 3: In this problem Ca^{2+} is limiting. We want to add just enough PO_4^{3-} to react with all the Ca^{2+}.

Step 4: We need to know how many moles of PO_4^{3-} will react with 0.25 mol Ca^{2+}. We can use the mole ratio from the balanced equation to calculate the moles of PO_4^{3-} which are needed.

$$0.25 \text{ mol } Ca^{2+} \times \frac{2 \text{ mol } PO_4^{3-}}{3 \text{ mol } Ca^{2+}} = 0.17 \text{ mol } PO_4^{3-}$$

So 0.17 mol PO_4^{3-} will react with 0.25 mol Ca^{2-}.

Step 5: We are asked for grams of Na_3PO_4, not moles of PO_4^{3-}, so convert moles of PO_4^{3-} to grams of Na_3PO_4. Each mole of Na_3PO_4 contains 1 mole of PO_4^{3-} ions. We can use the molar mass of Na_3PO_4 to convert from moles Na_3PO_4 to grams Na_3PO_4.

$$0.17 \text{ mol } PO_4^{3-} \times \frac{1 \text{ mol } Na_3PO_4}{1 \text{ mol } PO_4^{3-}} \times \frac{163.94 \text{ g } Na_3PO_4}{1 \text{ mol } Na_3PO_4} = 28 \text{ g } Na_3PO_4$$

18. We want to know how many grams of product, $Fe(OH)_3$, can be produced when two aqueous solutions are mixed together.

Step 1: Write and balance the equation for this reaction.

$$FeCl_3(aq) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + 3NaCl(aq)$$

From the balanced equation, write the net ionic equation.

$$Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$$

Step 2: We need to know the number of moles of reactant present in each solution. The solution of $FeCl_3$ contains 0.25 mol $FeCl_3$, and each mole of $FeCl_3$ contains 1 mole of Fe^{3+}.

$$0.25 \text{ mol } FeCl_3 \times \frac{1 \text{ mol } Fe^{3+}}{1 \text{ mol } FeCl_3} = 0.25 \text{ mol } Fe^{3+}$$

We need to know the number of moles of OH^- which are present.

$$V \times M = \text{moles NaOH}$$

$$1.2 \text{ L NaOH} \times \frac{0.85 \text{ mol NaOH}}{\text{L NaOH}} = 1.0 \text{ mol NaOH}$$

Each mole of NaOH contains 1 mole of OH^-.

$$1.0 \text{ mol NaOH} \times \frac{1 \text{ mol } OH^-}{1 \text{ mol NaOH}} = 1.0 \text{ mol } OH^-$$

Step 3: 0.25 mol Fe^{3+} is mixed with 1.0 mol OH^-. Because each mole of Fe^{3+} requires 3 moles of OH^-, 0.25 mol Fe^{3-} requires 3(0.25 mol OH^-) or 0.75 mol OH^-. Because we have 1.0 mol OH^-, the amount of product which forms is limited by the amount of Fe^{3+}.

Step 4: From the mole ratio, each mole of Fe^{3+} produces 1 mole of $Fe(OH)_3$.

$$0.25 \text{ mol } Fe^{3+} \times \frac{1 \text{ mol } Fe(OH)_3}{1 \text{ mol } Fe^{3+}} = 0.25 \text{ mol } Fe(OH)_3$$

Step 5: We want to know the number of grams of $Fe(OH)_3$, so use the molar mass of $Fe(OH)_3$ to convert from moles to grams.

$$0.25 \text{ mol } Fe(OH)_3 \times \frac{106.87 \text{ g } Fe(OH)_3}{1 \text{ mol } Fe(OH)_3} = 27 \text{ g } Fe(OH)_3$$

19. In this problem we are mixing a solution of HCl of known volume and molarity with a solution of NaOH of known molarity and an unknown volume. We are asked to determine the volume of NaOH which will react with the HCl. We can follow the same steps we have used previously.

Step 1: Write the balanced equation for this reaction.

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

Now, write the net ionic equation.

$$H^-(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Step 2: Calculate the moles of HCl using the formula V × M = moles.

$$150\ mL \times \frac{1\ L\ HCl}{1000\ mL} \times \frac{0.25\ mol\ H^+}{L\ HCl} = 0.038\ mol\ H^-$$

Step 3: This problem requires mixing just enough OH^- to react with all the H^+ which is present. The moles of H^- determine how much OH^- is to be added. The H^+ ions are limiting.

Step 4: From the net ionic equation we can determine how many moles of OH^- are needed to react with all the H^-.

$$0.038\ mol\ H^- \times \frac{1\ mol\ OH^-}{1\ mol\ H^+} = 0.03\ mol\ OH^-$$

Step 5: We now know the moles of OH^- and the molarity. We can use the formula V × M equals moles to calculate the volume of NaOH. Rearrange the equation to isolate V on one side.

$$V \times \frac{M}{M} = \frac{moles}{M}$$

$$V = \frac{moles}{M}$$

Now, substitute values into the equation.

$$V = \frac{0.038\ mol\ OH^-}{0.15\ mol\ NaOH/L\ NaOH}$$

$$V = 0.25\ L\ NaOH$$

So, 0.25 L of 0.15 M NaOH will completely react with 150 mL of 0.25 M HCl.

20.

material	**molar mass**	**equivalents**	**equivalent wt**
1.0 mol HCl	36.46	1	36.46
1.0 mol H_2SO_4	98.09	2	49.05
1.0 mol KOH	56.11	1	56.11

21. We want to calculate the normality of a solution of phosphoric acid in water. To do so, we need to know the number of equivalents of phosphoric acid present in 5.6 g phosphoric acid. The equivalent weight of phosphoric acid is

$$\text{equivalent weight } H_3PO_4 = \frac{\text{molar mass } H_3PO_4}{3}$$

$$\text{equivalent weight } H_3PO_4 = \frac{97.99 \text{ g}}{3}$$

$$\text{equivalent weight } H_3PO_4 = 32.66 \text{ g}$$

We can now calculate the equivalents of H_3PO_4 present in 5.6 g H_3PO_4.

$$5.6 \not{g}\ H_3PO_4 \times \frac{1 \text{ equiv } H_3PO_4}{32.66 \not{g}\ H_3PO_4} = 0.17 \text{ equiv } H_3PO_4$$

The definition of normality is $N = \frac{\text{equiv}}{L}$. We can use this equation to calculate the normality of the H_3PO_4 solution.

$$N = \frac{0.17 \text{ equiv } H_3PO_4}{125 \text{ mL}} \times \frac{1000 \text{ mL}}{L} = 1.36 \text{ equiv } H_3PO_4$$

This solution is 1.36 N H_3PO_4.