Advanced Stoichiometry

Stoichiometry is also useful in determining much more difficult concepts. Two that we can do in this class are calculating mass % and molarity. Let's see how:

Mass %

Remember that mass % is defined as:

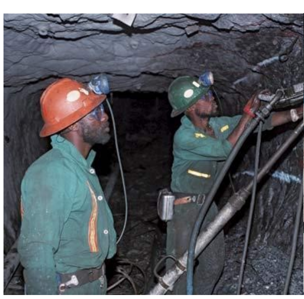
$$\frac{\text{Grams part}}{\text{Grams total}} \times 100\% = \text{Mass }\%$$

Let's say that we worked for a mining company that is interested in finding the element Platinum (Pt). Mining costs millions of dollars to set up. The company has to get tons of equipment and hundreds of people to a site that may or may not be accessible for any number of reasons (geography, weather, politics, etc.). They then have to figure out a way to get their raw material called "ore" to a processing plant to purify it. The company has to make sure that they are mining in a location that is going to be profitable or useful.

To do this, the company will most likely send out teams of scientists and workers to take samples of the area to find which area has the highest percentage of the material they are interested in. In many cases, they take portable equipment to analyze the soil samples and this is where Chemistry and stoichiometry become useful. For instance, platinum can be dissolved by a mixture of nitric and hydrochloric acids by the following equation. Nitrogen monoxide gas is produced.

$$3\ Pt\ (s)\ +\ 4\ HNO_3\ (aq)\ +\ 18\ HCl\ (aq) \longrightarrow 3\ H_2PtCl_6\ (aq)\ +\ 4\ NO\ (g)\ +\ 8\ H_2O\ (l)$$

If we know how much NO is produced, we can figure out how much Pt was in the sample! But we will have an additional piece of information in the puzzle due to the fact that we are analyzing the ore.



http://libcom.org/files/south-africa-miners.JPG

http://farm4.static.flickr.com/3655/3530176941_0219fe3294.jpg

http://www.khulsey.com/jewelry/metals_platinum_ore.jpeg

Platinum ore must be mined from the earth. It must then be separated out from the other rocks, minerals, metals, and other contaminants in the ore. Once purified, it can ultimately be used in things like jewelry.

Example 1:
A mining Chemist takes a 200 gram sample of Platinum ore and analyzes it to determine how much of it is Platinum. After reacting the sample with nitric and hydrochloric acid according to the reaction below, 0.72 grams of NO are produced. What is the mass % of Pt in the sample?

$$3\ Pt\ (s) + 4\ HNO_3\ (aq) + 18\ HCl\ (aq) \longrightarrow 3\ H_2PtCl_6\ (aq) + 4\ NO\ (g) + 8\ H_2O\ (l)$$

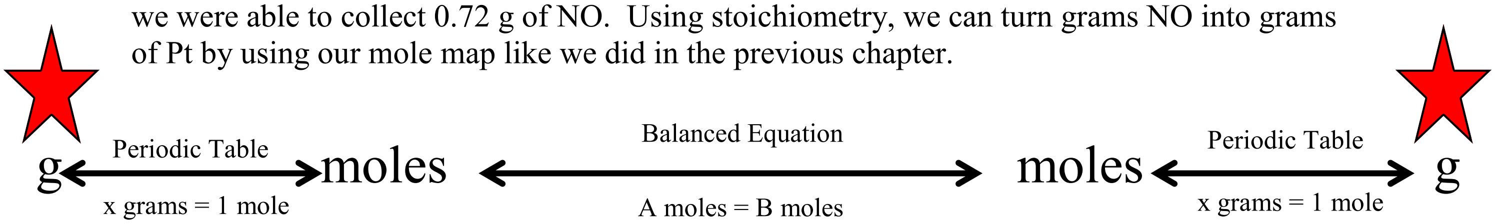
To answer this question, we must first make sure we know what we are looking for; the mass % of Pt:

$$\text{Mass \% Pt} = \frac{\text{grams Pt}}{\text{grams total}} \times 100\%$$

We need to know both the grams of Pt and the total grams. One of these is very easy, the total. Remember that the raw ore is comprised of both the Pt that we are interested in as well as other stuff we don't care about. All of this together is the total. Let's go ahead and put that number in:

$$\text{Mass \% Pt} = \frac{\text{grams Pt}}{\text{200 grams}} \times 100\%$$

How can we now get the grams of Pt? Looking at the other information we have, we see that we were able to collect 0.72 g of NO. Using stoichiometry, we can turn grams NO into grams of Pt by using our mole map like we did in the previous chapter.



NO

0.72 g NO (from given info)
1 mole NO = 30 g NO (from Per. Table)
3 moles Pt = 4 moles NO (from balanced equation)
1 mole Pt = 195.1 g (from Per. Table)

Pt

$$\frac{195.1\ \text{g Pt}}{1\ \text{mole Pt}} \times \frac{3\ \text{moles Pt}}{4\ \text{moles NO}} \times \frac{1\ \text{mole NO}}{30\ \text{g NO}} \times \frac{0.72\ \text{g NO}}{1} = 3.51\ \text{g Pt}$$

This, however, is not the answer we are looking for. We want the mass % of Pt in the ore. We need to take the 3.51 g Pt and plug it into the equation above to find the mass %:

$$\text{Mass \% Pt} = \frac{\text{grams Pt}}{\text{200 grams}} \times 100\% \qquad \text{Mass \% Pt} = \frac{\text{3.51 g Pt}}{\text{200 g total}} \times 100\%$$

Mass % Pt = 1.76%

Example 2:
A mining company wants to find our what the mass % of TiO_2 is in a sample. A 50 gram sample of ore is analyzed according to the equation below and 2.4 grams of Br_2 is produced. What is the mass % of TiO_2 in the ore?

$$3\,TiO_2 + 4\,BrF_3 \rightarrow 3\,TiF_4 + 2\,Br_2 + 3\,O_2$$

$$\text{Mass \% } TiO_2 = \frac{\text{grams } TiO_2}{\text{grams total}} \times 100\%$$

$$\text{Mass \% } TiO_2 = \frac{\text{grams } TiO_2}{\text{50 g total}} \times 100\%$$

g ← Periodic Table (x grams = 1 mole) → moles ← Balanced Equation (A moles = B moles) → moles ← Periodic Table (x grams = 1 mole) → g

Br_2 TiO_2

2.4 g Br_2 (from given info)
1 mole Br_2 = 159.8 g Br_2 (from Per. Table)
2 moles Br_2 = 3 moles TiO_2 (from balanced equation)
1 mole TiO_2 = 79.9 g TiO_2 (from Per. Table)

$$\frac{79.9\text{ g } TiO_2}{1\text{ mole } TiO_2} \times \frac{3\text{ moles } TiO_2}{2\text{ moles } Br_2} \times \frac{1\text{ mole } Br_2}{159.8\text{ g } Br_2} \times \frac{2.4\text{ g } Br_2}{1} = 1.8\text{ g } TiO_2$$

$$\text{Mass \% } TiO_2 = \frac{\text{grams } TiO_2}{\text{50 g total}} \times 100\% \qquad \text{Mass \% } TiO_2 = \frac{1.8\text{ g } TiO_2}{\text{50 g total}} \times 100\%$$

Mass % Pt = 3.6%

http://en.ferro-alloys.com/UserFiles/News/34-guitaikuang.jpg

http://www.manufacturer.com/images/product/www.alibaba.com/0415/u/1075474_Titanium_Metal_Ingots.jpg

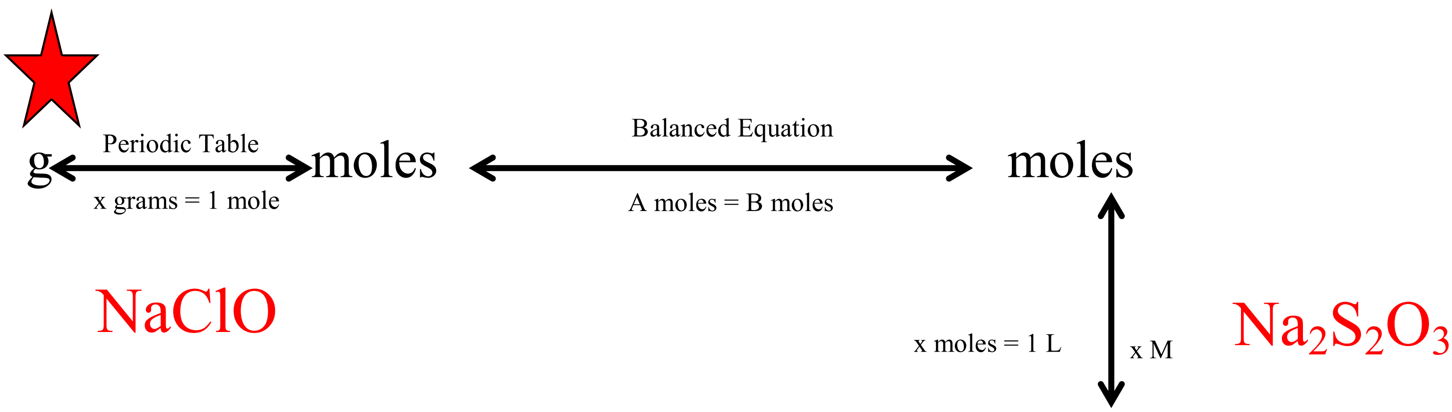
Raw titanium ore must be purified and then the TiO_2 can be turned into the titanium metal seen here.

Example 3:
A bottle of bleach is to be analyzed for the mass % of the active ingredient, NaClO by the equation listed below. It is found that a 2.0 gram sample of bleach requires 36.1 mL of 0.1 M $Na_2S_2O_3$ to reach the endpoint of the titration. What is the mass % of NaClO in the bleach?

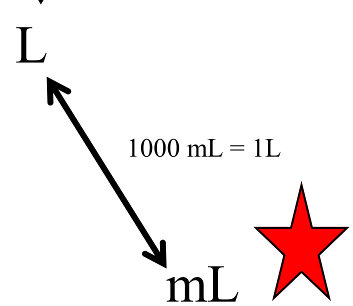
$$NaClO + 2\ Na_2S_2O_3 + 2\ HCl \longrightarrow 3\ NaCl + Na_2S_4O_6 + H_2O$$

$$\text{Mass \% NaClO} = \frac{\text{grams NaClO}}{\text{grams total}} \times 100\%$$

$$\text{Mass \% NaClO} = \frac{\text{grams NaClO}}{\text{2.0 g total}} \times 100\%$$



36.1 mL $Na_2S_2O_3$ (from given info)
1 mole NaClO = 74.5 g NaClO (from Per. Table)
1 mole NaClO = 2 moles $Na_2S_2O_3$ (from balanced equation)
0.1 moles $Na_2S_2O_3$ = 1 L $Na_2S_2O_3$ (from 0.1 M given)
1000 mL $Na_2S_2O_3$ = 1 L $Na_2S_2O_3$ (always true)



$$\frac{74.5\ \text{g NaClO}}{1\ \text{mole NaClO}} \times \frac{1\ \text{mole NaClO}}{2\ \text{moles}\ Na_2S_2O_3} \times \frac{0.1\ \text{moles}\ Na_2S_2O_3}{1\ \text{L}\ Na_2S_2O_3} \times \frac{1\ \text{L}\ Na_2S_2O_3}{1000\ \text{mL}\ Na_2S_2O_3} \times \frac{36.1\ \text{mL}\ Na_2S_2O_3}{1} = 0.134\ \text{g NaClO}$$

$$\text{Mass \% NaClO} = \frac{\text{grams NaClO}}{\text{2.0 g total}} \times 100\% \qquad \text{Mass \% NaClO} = \frac{\text{0.134 g NaClO}}{\text{2.0 g total}} \times 100\%$$

Mass NaClO = 6.7%

http://healthyinfluence.com/wordpress/wp-content/uploads/2009/06/white-green-clorox.gif

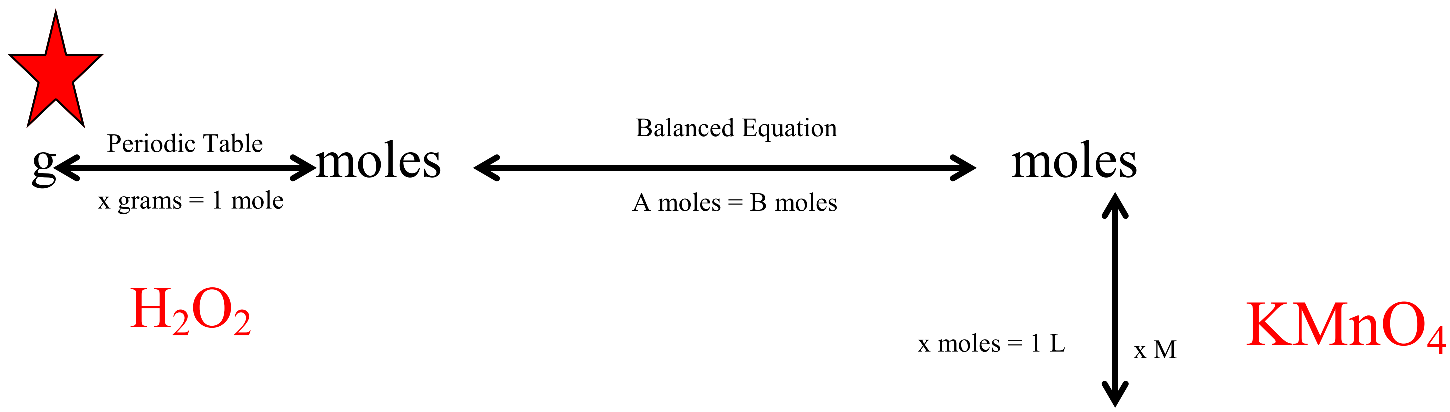
Bleach is mostly water. Only about 5-6% is the active bleaching agent of sodium hypochlorite; NaClO

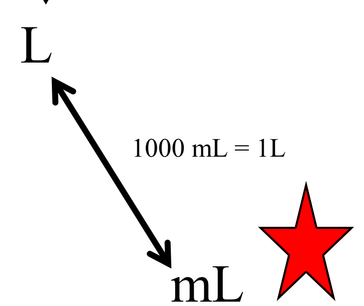
Example 4:
A bottle of peroxide is to be analyzed for the mass % of the active ingredient, H_2O_2 by the equation listed below. It is found that a 2.5 gram sample of peroxide requires 18.2 mL of 0.05 M $KMnO_4$ to reach the endpoint of a titration. What is the mass % of H_2O_2 in the sample?

$$2\ KMnO_4 + 3\ H_2SO_4 + 5\ H_2O_2 \longrightarrow 2\ MnSO_4 + 5\ O_2 + 8\ H_2O + K_2SO_4$$

$$\text{Mass \% } H_2O_2 = \frac{\text{grams } H_2O_2}{\text{grams total}} \times 100\%$$

$$\text{Mass \% } H_2O_2 = \frac{\text{grams } H_2O_2}{2.5\text{ g total}} \times 100\%$$





18.2 mL $KMnO_4$ (from given info)
1 mole H_2O_2 = 34 g H_2O_2 (from Per. Table)
2 moles $KMnO_4$ = 5 moles H_2O_2 (from balanced equation)
0.05 moles $KMnO_4$ = 1 L $KMnO_4$ (from 0.05 M given)
1000 mL $KMnO_4$= 1 L $KMnO_4$ (always true)

$$\frac{34\text{ g } H_2O_2}{1\text{ mole } H_2O_2} \times \frac{5\text{ moles } H_2O_2}{2\text{ moles } KMnO_4} \times \frac{0.05\text{ moles } KMnO_4}{1\text{ L } KMnO_4} \times \frac{1\text{ L } KMnO_4}{1000\text{ mL } KMnO_4} \times \frac{18.2\text{ mL } KMnO_4}{1} = 0.077\text{ g } H_2O_2$$

$$\text{Mass \% } H_2O_2 = \frac{\text{grams } H_2O_2}{2.5\text{ g total}} \times 100\% \qquad \text{Mass \% } H_2O_2 = \frac{0.077\text{ g } H_2O_2}{2.5\text{ g total}} \times 100\%$$

http://handyhints.gophercentral.com/wp-content/uploads/2009/05/hydrogen-peroxide.jpg

Mass H_2O_2 = 3.1%

Hydrogen peroxide is mostly water, about 97%. Only about 3% is actually H_2O_2.

Pirate Chemistry

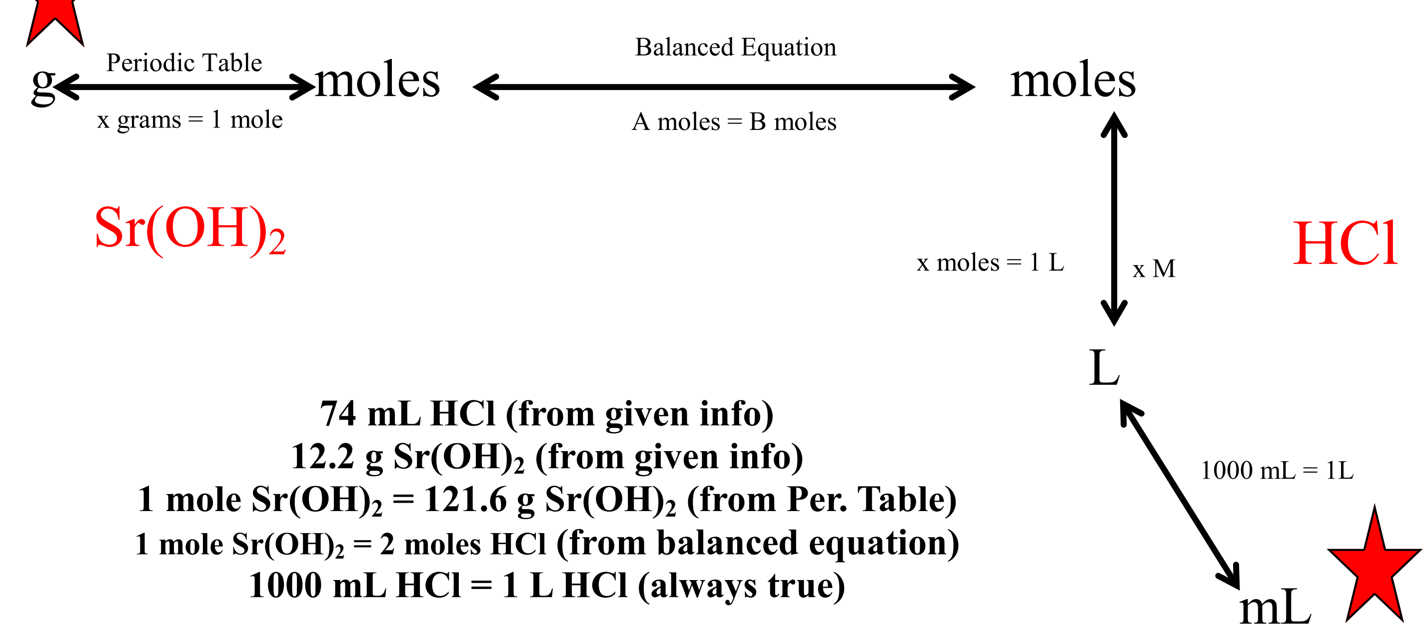
Molarity

Stoichiometry can also be used to calculate the molarity of a solution. Remember that molarity is defined as:

$$\text{Molarity} = \frac{\text{moles}}{\text{L}}$$

Example 5:
If 74 mL of HCl was used to neutralize 12.2 g of $Sr(OH)_2$ according to the equation below, what is the molarity (M) of the HCl?

$$Sr(OH)_2 + 2\ HCl \longrightarrow SrCl_2 + 2\ H_2O$$



74 mL HCl (from given info)
12.2 g $Sr(OH)_2$ (from given info)
1 mole $Sr(OH)_2$ = 121.6 g $Sr(OH)_2$ (from Per. Table)
1 mole $Sr(OH)_2$ = 2 moles HCl (from balanced equation)
1000 mL HCl = 1 L HCl (always true)

Remember we are trying to get moles of HCl and L of HCl to get:

$$\text{M HCl} = \frac{\text{moles HCl}}{\text{L HCl}}$$

$$\frac{2\ \text{moles HCl}}{1\ \text{mole}\ Sr(OH)_2} \times \frac{1000\ \text{mL HCl}}{1\ \text{L HCl}} \times \frac{1\ \text{mole}\ Sr(OH)_2}{121.6\ \text{g}\ Sr(OH)_2} \times \frac{12.2\ \text{g}\ Sr(OH)_2}{1} \times \frac{1}{74\ \text{mL HCl}} = 2.71\ \frac{\text{moles}}{\text{L}}$$

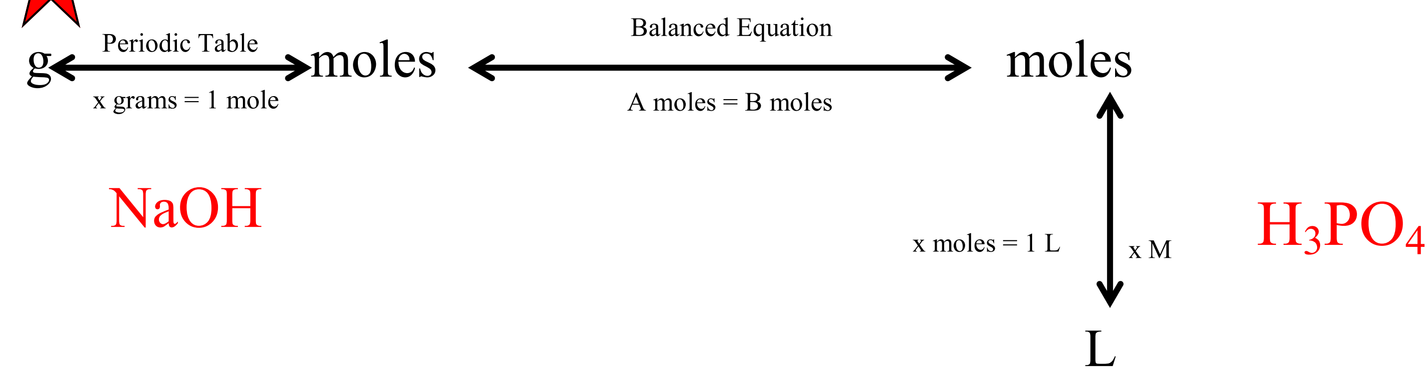
Or

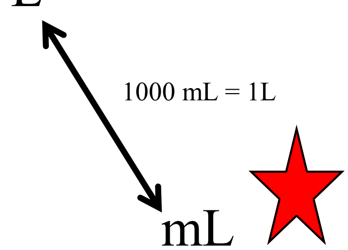
2.71 M

Remember to set up what you want where you want it first.

Example 6:
If 23 mL of H_3PO_4 were needed to neutralize 2.5 grams of NaOH, what is the concentration (Molarity, M) or the H_3PO_4

$$3\ NaOH + H_3PO_4 \longrightarrow Na_3PO_4 + 3\ H_2O$$





23 mL H_3PO_4 (from given info)
2.5 g NaOH (from given info)
1 mole NaOH = 40 g NaOH(from Per. Table)
1 mole H_3PO_4 = 3 moles NaOH (from balanced equation)
1000 mL H_3PO_4 = 1 L H_3PO_4 (always true)

Remember we are trying to get moles of H_3PO_4 and L of H_3PO_4 to get:

$$M\ H_3PO_4 = \frac{\text{moles } H_3PO_4}{\text{L } H_3PO_4}$$

$$\frac{1\text{ mole } H_3PO_4}{3\text{ moles NaOH}} \times \frac{1000\text{ mL } H_3PO_4}{1\text{ L } H_3PO_4} \times \frac{1\text{ mole NaOH}}{40\text{ g NaOH}} \times \frac{2.5\text{ g NaOH}}{1} \times \frac{1}{23\text{ mL } H_3PO_4} = 0.906\ \frac{\text{moles}}{\text{L}}$$

Or

0.906 M

Phosphoric Acid, H_3PO_4, is produced to the tune of 10 million tons per year in the USA. The vast majority of it is used to make fertilizers while the rest is used in detergents and insecticides. It is even present in small quantities in soft drinks like Coca-Cola!

http://www.chemicalindia.co.in/images/phosphoric_acid.jpg

Questions

1. What is the mass % of Fe_2O_3 in a 250 gram sample of iron ore that required 5.6 grams of H_2 to react all the Fe_2O_3?

$$Fe_2O_3 + 3\ H_2 \longrightarrow 3\ H_2O + 2\ Fe$$

2. What is the mass % of Bi_2O_3 in a 400 gram sample of bismuth ore that produced 34 grams of Bi upon complete reaction?

$$Bi_2O_3 + 3\ C \longrightarrow 2\ Bi + 3\ CO$$

3. What is the mass % of NH_3 in 25 gram sample of ammonia solution that required 12 mL of 3 M H_2SO_4 to neutralize?

$$2\ NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

4. What is the mass % of $CaBr_2$ in a 75 gram solution if complete reaction of the solution produced 23 grams of AgBr?

$$CaBr_2 + 2\ AgNO_3 \longrightarrow 2\ AgBr + Ca(NO_3)_2$$

5. What is the molarity (moles/L) of an HCl solution if it required 36 mL of HCl to neutralize 8.2 grams of $Ca(OH)_2$?

$$2\ HCl + Ca(OH)_2 \longrightarrow CaCl_2 + 2\ H_2O$$

6. What is the molarity (moles/L) of an $HC_2H_3O_2$ solution if 61 mL of $HC_2H_3O_2$ neutralized 2.0 grams of NaOH?

$$HC_2H_3O_2 + NaOH \longrightarrow H_2O + NaC_2H_3O_2$$