CHE1031: Guide to limiting reactants, theoretical yield and titration

Approach for limiting reactants and theoretical yield problems

Steps

1. Start with a balanced chemical equation.
2. Start a pair of railroad track conversion problems.
   (a) Reactant A to product of interest
   (b) Reactant B to product of interest
3. The reactant that produces the lowest yield of product (in either grams or moles) is limiting.
4. Theoretical yields of product are calculated (see step 2) in either grams or moles.
5. Excess reactant can be calculated by using stoichiometry to determine exactly how much of the reactant present in excess is needed to react with the limiting reactant.
6. Percent yield = (actual/theoretical)(100)

Precipitation example:

Solutions of sodium carbonate and silver nitrate react to form solid silver carbonate and aqueous sodium nitrate. If a solution containing 3.50 g of sodium carbonate is mixed with one containing 5.00 g of silver nitrate, what is the theoretical yield of silver carbonate in grams? How many grams of excess reactant are left? If the actual yield is 4.00 g, what is the percent yield?

1. $Na_2(CO_3)\,(aq) + 2Ag(NO_3)\,(aq) \rightarrow Ag_2(CO_3)\,(ppt) + 2Na(NO_3)\,(aq)$

   $Na_2(CO_3)$ = 105.98 g/mol
   $Ag(NO_3)$ = 169.88 g/mol
   $Ag_2(CO_3)$ = 275.74 g/mol

2. Pair of conversion problems:

   (a) $$3.50\text{ g } Na_2(CO_3)\;\frac{1\text{ mol } Na_2(CO_3)}{105.98\text{ g}}\;\frac{1\text{ mol } Ag_2(CO_3)}{1\text{ mol } Na_2(CO_3)}\;\frac{275.74\text{ g}}{1\text{ mol } Ag_2(CO_3)} = 9.11\text{ g}$$

   (b) $$5.00\text{ g } Ag(NO_3)\;\frac{1\text{ mol } Ag(NO_3)}{169.88\text{ g}}\;\frac{1\text{ mol } Ag_2(CO_3)}{2\text{ mol } Ag(NO_3)}\;\frac{275.74\text{ g}}{1\text{ mol } Ag_2(CO_3)} = \mathbf{4.06\text{ g}^{**}}$$

3. $Ag(NO_3)$ produces a lower yield and so it is the limiting reactant.

4. The theoretical yield is 4.06 g of $Ag_2(CO_3)$.

5. Calculation of the mass of $Na_2(CO_3)$ needed to react with all limiting reactant:

   $$5.00\text{ g } Ag(NO_3)\;\frac{1\text{ mol } Ag(NO_3)}{169.88\text{ g}}\;\frac{1\text{ mol } Na_2(CO_3)}{2\text{ mol } Ag(NO_3)}\;\frac{105.98\text{ g}}{1\text{ mol } Na_2(CO_3)} = 1.56\text{ g } Na_2(CO_3)$$

   So, leftover excess reactant = 3.50 g provided – 1.56 g needed = 1.94 g of $Na_2(CO_3)$

6. Percent yield = (4.00 g/4.06 g)(100) = 98.5 %

Neutralization examples:
10 mL of 0.8 M phosphoric acid react with 50 mL of 1.6 M sodium hydroxide. Which is the limiting reactant? What is the theoretical yield of water in grams? How many mL of excel reactant remain?

1. $H3(PO4) + 3Na(OH) \rightarrow 3H2O + Na3(PO4)$

2. Pair of conversion problems:

(a) $\frac{0.010\text{ L} \quad 0.8\text{ mol H3(PO4)} \quad 3\text{ mol H2O} \quad 18.02\text{ g}}{\quad 1\text{ L} \quad 1\text{ mol H3(PO4)} \quad 1\text{ mol H2O}} = 0.43\text{ g H2O}$

(b) $\frac{0.050 \quad 1.6\text{ mol Na(OH)} \quad 3\text{ mol H2O} \quad 18.02\text{ g}}{\quad 1\text{ L} \quad 3\text{ mol Na(OH)} \quad 1\text{ mol H2O}} = 1.4\text{ g H2O}$

3. H3(PO4) produces a lower yield and so it is the limiting reactant.

4. The theoretical yield is 0.43 g of H2O.

5. Calculation of the mass of Na(OH) needed to react with all limiting reactant:

$\frac{0.010\text{ L} \quad 0.8\text{ mol H3(PO4)} \quad 3\text{ mol Na(OH)} \quad 1\text{ L}}{\quad 1\text{ L} \quad 1\text{ mol H3(PO4)} \quad 1.6\text{ mol Na(OH)}} = 15\text{ mL Na(OH)}$

So excess Na(OH) = 50 mL provided – 15 mL needed = 35 mL excess Na(OH)

Titration
If 26 mL of 2.5 M phosphoric acid are required to titrate 50 mL of NaOH, what is the concentration of the Na(OH)?

Steps:
1. Create a balanced chemical equation.
2. Associate information (numbers from the word problem) with the equation.
3. Identify the standard solution (you know both concentration and volume).
4. Set up a conversion that calculates:
   - Moles of standard reactant;
   - Moles of the other reactant; and
   - Either volume or molarity of other reactant, as asked in the problem.

1. $H3(PO4) + 3Na(OH) \rightarrow Na3(PO4) + 3H2O$

2. 26 mL   50 mL
   2.5 M   X M

3. H3(PO4) is the standard solution because we know more about it.

4. $\frac{0.026\text{ L} \quad 2.5\text{ mol H3(PO4)} \quad 3\text{ mol Na(OH)}}{\quad 1\text{ L} \quad 1\text{ mol H3(PO4)} \quad 0.050\text{ L Na(OH)}} = 3.9\text{ M Na(OH)}$