



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?



$$\text{Na}_2(\text{CO}_3) = 105.98 \text{ g/mol}$$

$$\text{Ag}(\text{NO}_3) = 169.88 \text{ g/mol}$$

$$\text{Ag}_2(\text{CO}_3) = 275.74 \text{ g/mol}$$

2. Pair of conversion problems:

$$(a) \frac{3.50 \text{ g Na}_2(\text{CO}_3)}{105.98 \text{ g}} \cdot \frac{1 \text{ mol Na}_2(\text{CO}_3)}{1 \text{ mol Na}_2(\text{CO}_3)} \cdot \frac{1 \text{ mol Ag}_2(\text{CO}_3)}{1 \text{ mol Na}_2(\text{CO}_3)} \cdot \frac{275.74 \text{ g}}{1 \text{ mol Ag}_2(\text{CO}_3)} = 9.11 \text{ g}$$

$$(b) \frac{5.00 \text{ g Ag}(\text{NO}_3)}{169.88 \text{ g}} \cdot \frac{1 \text{ mol Ag}(\text{NO}_3)}{2 \text{ mol Ag}(\text{NO}_3)} \cdot \frac{1 \text{ mol Ag}_2(\text{CO}_3)}{1 \text{ mol Ag}_2(\text{CO}_3)} \cdot \frac{275.74 \text{ g}}{1 \text{ mol Ag}_2(\text{CO}_3)} = 4.06 \text{ g}^{**}$$

3. $\text{Ag}(\text{NO}_3)$ produces a lower yield and so it is the limiting reactant.

4. The theoretical yield is 4.06 g of $\text{Ag}_2(\text{CO}_3)$.

5. Calculation of the mass of $\text{Na}_2(\text{CO}_3)$ needed to react with all limiting reactant:

$$\frac{5.00 \text{ g Ag}(\text{NO}_3)}{169.88 \text{ g}} \cdot \frac{1 \text{ mol Ag}(\text{NO}_3)}{2 \text{ mol Ag}(\text{NO}_3)} \cdot \frac{1 \text{ mol Na}_2(\text{CO}_3)}{1 \text{ mol Na}_2(\text{CO}_3)} \cdot \frac{105.98 \text{ g}}{1 \text{ mol Na}_2(\text{CO}_3)} = 1.56 \text{ g Na}_2(\text{CO}_3)$$

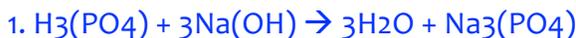
So, leftover excess reactant = 3.50 g provided – 1.56 g needed = 1.94 g of $\text{Na}_2(\text{CO}_3)$

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 excess reactant remain?



2. Pair of conversion problems:

$$(a) \frac{0.010 \text{ L}}{1 \text{ L}} \cdot \frac{0.8 \text{ mol H}_3(\text{PO}_4)}{1 \text{ mol H}_3(\text{PO}_4)} \cdot \frac{3 \text{ mol H}_2\text{O}}{1 \text{ mol H}_3(\text{PO}_4)} \cdot \frac{18.02 \text{ g}}{1 \text{ mol H}_2\text{O}} = 0.43 \text{ g H}_2\text{O}$$

$$(b) \frac{0.050 \text{ L}}{1 \text{ L}} \cdot \frac{1.6 \text{ mol Na}(\text{OH})}{3 \text{ mol Na}(\text{OH})} \cdot \frac{3 \text{ mol H}_2\text{O}}{3 \text{ mol Na}(\text{OH})} \cdot \frac{18.02 \text{ g}}{1 \text{ mol H}_2\text{O}} = 1.4 \text{ g H}_2\text{O}$$

3. $\text{H}_3(\text{PO}_4)$ produces a lower yield and so it is the limiting reactant.

4. The theoretical yield is 0.43 g of H_2O .

5. Calculation of the mass of $\text{Na}(\text{OH})$ needed to react with all limiting reactant:

$$\frac{0.010 \text{ L}}{1 \text{ L}} \cdot \frac{0.8 \text{ mol H}_3(\text{PO}_4)}{1 \text{ mol H}_3(\text{PO}_4)} \cdot \frac{3 \text{ mol Na}(\text{OH})}{1 \text{ mol H}_3(\text{PO}_4)} \cdot \frac{1 \text{ L}}{1.6 \text{ mol Na}(\text{OH})} = 15 \text{ mL Na}(\text{OH})$$

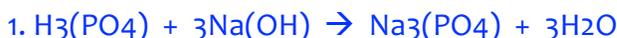
So excess $\text{Na}(\text{OH}) = 50 \text{ mL provided} - 15 \text{ mL needed} = 35 \text{ mL excess Na}(\text{OH})$

Titration

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

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.



2. $\frac{26 \text{ mL}}{2.5 \text{ M}} \quad \frac{50 \text{ mL}}{X \text{ M}}$

3. $\text{H}_3(\text{PO}_4)$ is the standard solution because we know more about it.

$$4. \frac{0.026 \text{ L}}{1 \text{ L}} \cdot \frac{2.5 \text{ mol H}_3(\text{PO}_4)}{1 \text{ mol H}_3(\text{PO}_4)} \cdot \frac{3 \text{ mol Na}(\text{OH})}{1 \text{ mol H}_3(\text{PO}_4)} \cdot \frac{1 \text{ L}}{0.050 \text{ L Na}(\text{OH})} = 3.9 \text{ M Na}(\text{OH})$$