% Yield

A student placed 5.00 g Na in a flask and added enough Cl_2 for the Na to react completely. The student collected 10.00 g NaCl.

What percent yield did the student achieve? (Which means how much product did the student collect as compared to the theoretical maximum.)

So, $\% \text{ yield} = \frac{\text{amt. isolated}}{\text{theoretical amt.}} \times 100$

What amounts? Grams (it is possible to use grams, but most people get very confused when they try to use grams)? No! compare moles. (Actually, the important thing is to always compare like units. Compare moles to moles, or grams to grams, but never grams to moles.)

To compare moles first write the balanced equation.

$$2\ Na + Cl_2 \longrightarrow 2\ NaCl$$

How many moles of Na of Na did the student use?

$$5.00\ g \times \frac{1\ mol\ Na}{22.99\ g\ Na} = 0.2175\ mol\ Na$$

So, how many moles of NaCl should the student be able to make?

$$0.2175\ mol\ Na \times \frac{2\ mol\ NaCl}{2\ mol\ Na} = 0.2175\ mol\ NaCl\ (\text{theoretical limit})$$

So, we know how much the student could have made, but how much did the student make?

$$10.00\ g\ NaCl \times \frac{1\ mole\ NaCl}{58.443\ g\ NaCl} = 0.17110\ mol\ NaCl\ (\text{isolated})$$

So, $\frac{0.17110\ mol\ NaCl\ (\text{collected})}{0.2175\ mol\ NaCl\ (\text{theoretical})} \times 100 = 78.7\ \%\ \text{yield}$

Limiting Reagents

It is rare that two chemicals are mixed together in exactly the right amount. Often there is not quite enough of one chemical; this chemical is the limiting reagent.

For example if you have only 1 scoop of ice cream left, no matter how much milk you have you can only make 1 milk shake.

1 cup milk + 1 scoop ice cream ——> 1 milk shake

A chemist combines 3.00 g Ca and 13.00 g Br_2. How much $CaBr_2$ can the chemist make?

Once again, write the balanced equation first.

$$Ca + Br_2 \longrightarrow CaBr_2$$

How much of each material does the chemist have?

$$3.00 \text{ g Ca} \times \frac{1 \text{ mol Ca}}{40.08 \text{ g Ca}} = 0.07485 \text{ mol Ca}$$

$$13.00 \text{ g } Br_2 \times \frac{1 \text{ mol } Br_2}{159.808 \text{ g mol}} = 0.08135 \text{ mol } Br_2$$

Determine the ratio which the reactants react. In this case 1 mol Ca reacts with 1 mol Br_2. There is less Ca than there is Br_2 so the Ca is the limiting reagent. So, the chemist can make only 0.0749 mol $CaBr_2$.

For the reaction of Na with Br_2; 2 mol of Na reacts with 1 mol of Br_2 to make 2 mol of NaBr.

$$2\ Na + Br_2 \longrightarrow 2\ NaBr$$

If 1.3 mol Na are mixed with 0.60 mol of Br_2 how much NaBr will be formed?

$$1.3 \text{ mol Na} \times \frac{1 \text{ mol } Br_2}{2 \text{ mol Na}} = 0.65 \text{ mol } Br_2$$

But there is only 0.60 mol Br_2 present (which is not enough for the amount of Na to be used), so the amount of Br_2 is going to limit the reaction. There will be extra sodium remaining when the bromine is consumed.

So, the amount of NaBr produced will be

$$0.60 \text{ mol } Br_2 \times \frac{2 \text{ mol NaBr}}{1 \text{ mol } Br_2} = 1.2 \text{ mol NaBr}$$

How much Na remains unreacted?

$$0.60 \text{ mole } Br_2 \times \frac{2 \text{ mol Na}}{1 \text{ mol } Br_2} = 1.2 \text{ mol Na consumed}$$

1.3 mol Na - 1.2 mol Na = 0.1 mol Na remains.

12.5 g of sodium sulfate and 35.0 g of barium nitrate react to form sodium nitrate and barium sulfate. 9.5 g of barium sulfate were collected. Determine the percent yield of barium sulfate.

$$Na_2SO_4 + Ba(NO_3)_2 \longrightarrow 2\ NaNO_3 + BaSO_4$$

To determine % yield the actual yield and the theoretical maximum yield must be known.

Actual yield = 9.5 g barium sulfate

The reagent that limits the reaction has to be determined in order to determine the theoretical yield.

Sometimes it is just easier to determine the theoretical yield possible from each reagent, and the lower yield is the theoretical yield.

$$35.0\text{ g }Ba(NO_3)_2 \times \frac{1\text{ mol }Ba(NO_3)_2}{261.34\text{ g }Ba(NO_3)_2} \times \frac{1\text{ mol }BaSO_4}{1\text{ mol }Ba(NO_3)_2} = 0.134\text{ mol }BaSO_4$$

There is enough $Ba(NO_3)_2$ to make 0.134 mol $BaSO_4$.

$$12.5\text{ g }Na_2SO_4 \times \frac{1\text{ mol }Na_2SO_4}{142.04\ Na_2SO_4\text{ g}} \times \frac{1\text{ mol }BaSO_4}{1\text{ mol }Na_2SO_4} = 0.0880\text{ mol }BaSO_4$$

However, there is only enough Na_2SO_4 to make 0.088 mol $BaSO_4$.

Once the supply of Na_2SO_4 is exhausted the reaction will stop.

Theoretical yield is 0.0880 mol $BaSO_4$

To determine % yield you must compare the same units; i.e., compare moles to moles, or grams to grams, but never grams to moles.

$$\%\text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

Since the actual yield is reported in grams that number must be converted to moles.

$$9.5\text{ g BaSO}_4 \times \frac{1\text{ mol BaSO}_4}{233.39\text{ g BaSO}_4} = 0.0407\text{ mol BaSO}_4$$

$$\%\text{ yield} = \frac{0.0407\text{ mol BaSO}_4}{0.0880\text{ mol BaSO}_4} \times 100$$

$$= 46.25$$

$$\%\text{ yield} = 46\ \%$$

If Na_2SO_4 is the limiting reagent how much $Ba(NO_3)_2$ remains after the reaction is completed.

The amt. remaining after the reaction is simply the amt. at the beginning of the reaction minus the amt. consumed during the reaction.

So, how much $Ba(NO_3)_2$ did we start with?

$$35.0\text{ g Ba(NO}_3)_2 \times \frac{1\text{ mol Ba(NO}_3)_2}{261.34\text{ g Ba(NO}_3)_2} = 0.134\text{ mol Ba(NO}_3)_2$$

How much was consumed?

$$12.5\text{ g Na}_2\text{SO}_4 \times \frac{1\text{ mol Na}_2\text{SO}_4}{142.04\text{ Na}_2\text{SO}_4\text{ g}} \times \frac{1\text{ mol Ba(NO}_3)_2}{1\text{ mol Na}_2\text{SO}_4} = 0.0880\text{ mol Ba(NO}_3)_2\text{ consumed}$$

so,

$$\text{amt. remaining} = 0.134\text{ mol Ba(NO}_3)_2 - 0.0880\text{ mol Ba(NO}_3)_2$$

$$\text{amt. remaining} = 0.046\text{ mol Ba(NO}_3)_2$$

How do you know when the problem is a limiting reagent problem or when a problem is simply a percent yield problem.

A simple percent yield problem is often worded

5.6 g of Na_2SO_4 react with excess $Ba(NO_3)_2$ to produce 5.1 g $BaSO_4$. Determine the % yield of $BaSO_4$.

or

5.6 g of Na_2SO_4 react with enough $Ba(NO_3)_2$ to completely consume the Na_2SO_4. 5.1 g $BaSO_4$ were produced. Determine the % yield of $BaSO_4$.

> The words "excess $Ba(NO_3)_2$" or "enough $Ba(NO_3)_2$ to completely consume the Na_2SO_4" are there to tell you that $Ba(NO_3)_2$ is **not** the limiting reagent; Na_2SO_4 is the limiting reagent. So, determine the % yield based on the amount of Na_2SO_4 used.

Limiting reagent problems always list the amounts of both of the reagents. Then it is up to you to determine which reagent is the limiting reagent.

> If the amount of only one reagent is given then the problem is a straight forward percent yield problem.
>
> If the amounts of two, or more, reagents are given then the problem is a percent yield problem with a limiting reagent problem.