

## % Yield

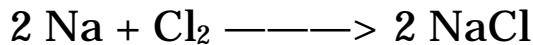
A student placed 5.00 g Na in a flask and added enough Cl<sub>2</sub> for the Na to react completely. The student collected 10.00 g NaCl.

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

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

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.



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

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

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

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

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

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

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

## 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.



A chemist combines 3.00 g Ca and 13.00 g Br<sub>2</sub>. How much CaBr<sub>2</sub> can the chemist make?

Once again, write the balanced equation first.



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<sub>2</sub>. There is less Ca than there is Br<sub>2</sub> so the Ca is the limiting reagent. So, the chemist can make only 0.0749 mol CaBr<sub>2</sub>.

For the reaction of Na with Br<sub>2</sub>; 2 mol of Na reacts with 1 mol of Br<sub>2</sub> to make 2 mol of NaBr.



If 1.3 mol Na are mixed with 0.60 mol of Br<sub>2</sub> 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<sub>2</sub> present (which is not enough for the amount of Na to be used), so the amount of Br<sub>2</sub> 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

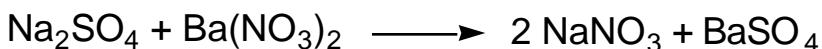
$$0.60 \text{ mol Br}_2 \times \frac{2 \text{ mol NaBr}}{1 \text{ mol Br}_2} = 1.2 \text{ mol NaBr}$$

How much Na remains unreacted?

$$0.60 \text{ mole Br}_2 \times \frac{2 \text{ mol Na}}{1 \text{ mol Br}_2} = 1.2 \text{ mol Na consumed}$$

$$1.3 \text{ mol Na} - 1.2 \text{ mol Na} = 0.1 \text{ mol Na remains.}$$

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.



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.

$$35.0 \text{ g Ba}(\text{NO}_3)_2 \times \frac{1 \text{ mol Ba}(\text{NO}_3)_2}{261.34 \text{ g Ba}(\text{NO}_3)_2} \times \frac{1 \text{ mol BaSO}_4}{1 \text{ mol Ba}(\text{NO}_3)_2} = 0.134 \text{ mol BaSO}_4$$

There is enough  $\text{Ba}(\text{NO}_3)_2$  to make 0.134 mol  $\text{BaSO}_4$ .

$$12.5 \text{ g Na}_2\text{SO}_4 \times \frac{1 \text{ mol Na}_2\text{SO}_4}{142.04 \text{ g Na}_2\text{SO}_4} \times \frac{1 \text{ mol BaSO}_4}{1 \text{ mol Na}_2\text{SO}_4} = 0.0880 \text{ mol BaSO}_4$$

However, there is only enough  $\text{Na}_2\text{SO}_4$  to make 0.088 mol  $\text{BaSO}_4$ .

Once the supply of  $\text{Na}_2\text{SO}_4$  is exhausted the reaction will stop.

**Theoretical yield is 0.0880 mol  $\text{BaSO}_4$**

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  $\text{Na}_2\text{SO}_4$  is the limiting reagent how much  $\text{Ba}(\text{NO}_3)_2$  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  $\text{Ba}(\text{NO}_3)_2$  did we start with?

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

How much was consumed?

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

so,

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

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

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<sub>2</sub>SO<sub>4</sub> react with excess Ba(NO<sub>3</sub>)<sub>2</sub> to produce 5.1 g BaSO<sub>4</sub>. Determine the % yield of BaSO<sub>4</sub>.**

or

**5.6 g of Na<sub>2</sub>SO<sub>4</sub> react with enough Ba(NO<sub>3</sub>)<sub>2</sub> to completely consume the Na<sub>2</sub>SO<sub>4</sub>. 5.1 g BaSO<sub>4</sub> were produced. Determine the % yield of BaSO<sub>4</sub>.**

The words “excess Ba(NO<sub>3</sub>)<sub>2</sub>” or “enough Ba(NO<sub>3</sub>)<sub>2</sub> to completely consume the Na<sub>2</sub>SO<sub>4</sub>” are there to tell you that Ba(NO<sub>3</sub>)<sub>2</sub> is **not** the limiting reagent; Na<sub>2</sub>SO<sub>4</sub> is the limiting reagent. So, determine the % yield based on the amount of Na<sub>2</sub>SO<sub>4</sub> 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.**