**A Comment before starting:**

Just a bit below, I'm going to tell you (several times) how to determine the limiting reagent in a chemistry problem. I certainly hope it is something you pay attention to and remember. Figuring out which substance is the limiting reagent is an area that many students struggle with.

You will see the word "excess" used in this section and in the problems. It is used several different ways:

a) **Compound A reacts with an excess of compound B.** In this case, mentally set compound B aside for the moment. Since it is "in excess," this means there is more than enough of it. The other compound will run out first.

b) **20 grams of A and 20 grams of B react. Which is in excess?** What we will do below is find out which substance runs out first (called the limiting reagent). Obviously (I hope), the other compound is seen to be in excess.

c) **After 20 gm. of A and 20 gm. of B react, how much of the excess compound remains.** To answer this problem, we would subtract the limiting reagent amount from the excess amount.

**What is the Limiting Reagent?**

It is simply the substance in a chemical reaction that runs out first. It seems to besimple, but it does cause people problems. Let's try a simple example.

Reactant A is a test tube. I have 20 of them.
Reactant B is a stopper. I have 30 of them.

Product C is a stoppered test tube.

The reaction is:

A + B ---> C

test tube plus stopper gives stoppered test tube.

So now we let them "react." The first stopper goes in, the second goes in and so on. Step by step we use up stoppers and test tubes (the amounts go down) and make stoppered test tubes (the amount goes up).

Suddently, we run out of one of the "reactants." Which one? That's right. We run out of test tubes first. Seems obvious, doesn't it? We had 20 test tubes, but we had 30 stoppers. So when the test tubes are used up, we have 10 stoppers sitting there unused. And we also have 20 test tubes with stoppers firmly inserted.

So, which "reactant" is limiting and which is in excess? The test tubes are limiting (they ran out first) and the stoppers are in excess (we have some left over when the limiting reagent ran out).

There is a technique to determine the limiting reagent in chemical problems. It's discussed as part of the solution to the first example. Make sure you take a close look at it.

**Example #1:** Here's a nice limiting reagent problem we will use for discussion. Consider the reaction:

2 Al + 3I2 ------> 2 AlI3

Determine the limiting reagent and the theoretical yield of the product if one starts with:

a) 1.20 mol Al and 2.40 mol iodine.
b) 1.20 g Al and 2.40 g iodine
c) How many grams of Al are left over in part b?

**Solution for part a:**

We already have moles as the unit, so we use those numbers directly.

Here is how to find out the limiting reagent:

take the moles of each substance and divide it by the coefficient of the balanced equation. The substance that has the smallest answer is the limiting reagent.

Let's say that again:

**to find the limiting reagent, take the moles of each substance and divide it by the coefficient of the balanced equation. The substance that has the smallest answer is the limiting reagent.**

You're going to need that technique, so remember it.

By the way, did you notice that I bolded the technique to find the limiting reagent? I did this so as to emphasize its importance to you when learning how to do limiting reagent problems.

Resuming with the problem solution:

For aluminum: 1.20 / 2 = 0.60
For iodine: 2.40 / 3 = 0.80

The lowest number indicates the limiting reagent. Aluminum will run out first in part a.

Why? 1.20/2 means there are 0.60 "groupings" of 2 and 2.40/3 means there are 0.80 "groupings" of 3. If they ran out at the same time, we'd need one "grouping" of each. Since there is less of the "grouping of 2," it will run out first.

If you're not sure what I just said, that's OK. The technique works, so remember it and use it.

The second part of the question "theoretical yield" depends on finding out the limiting reagent. Once we do that, it becomes a stoichiometric calculation.

Al and AlI3 stand in a one-to-one molar relationship, so 1.20 mol of Al produces 1.20 mol of AlI3. Notice that the amount of I2 does not play a role, since it is in excess.

**Solution for part b:**

Since we have grams, we must first convert to moles. The we solve just as we did in part a just above.

For the mole calculation:

aluminum is 1.20 g / 26.98 g mol¯1 = 0.04477 mol
iodine is 2.4 g / 253.8 g mol¯1 = 0.009456 mol

To determine the limiting reagent:

aluminum is 0.04477 / 2 = 0.02238
iodine is 0.009456 / 3 = 0.003152

The lower number is iodine, so we have identified the limiting reagent.

Finally, we have to do a calculation and it will involve the iodine, NOT the aluminum.

I2 and AlI3 stand in a three-to-two molar relationship, so 0.009456 mol of I2 produces 0.006304 mol of AlI3. Again, notice that the amount of Al does not play a role, since it is in excess.

From here figure out the grams of AlI3 and you have your answer.

**Solution for part c:**

Since we have moles, we calculate directly and then convert to grams.

Al and I2 stand in a two-to-three molar relationship, so 0.009456 mol of I2 uses 0.006304 mol of Al.

Convert this aluminum amount to grams and subtract it from 1.20 g and that's the answer.

Just above was some discussion on how to determine the limiting reagent in a chemistry problem. Through experience, I have learned that this particular thing (determine the limiting reagent) is a real stumbling block for students. You might have to resort to memorizing what to do without fully understanding the reasoning behind it.

**Example #2:** 15.00 g aluminum sulfide and 10.00 g water react until the limiting reagent is used up. Here is the balanced equation for the reaction:

Al2S3 + 6 H2O ---> 2Al(OH)3 + 3 H2S

(A) Which is the limiting reagent?
(B) What is the maximum mass of H2S which can be formed from these reagents?
(C) How much excess reagent remains after the reaction is complete?

Some comments first:

The key to this problem is the limiting reagent, part A. Once you know that, part B becomes "How much H2S can be made from the limiting reagent?" Part C becomes two connected questions: first, "How much Al2S3 is used up when reacting with the limiting reagent?" then second, "What is 15.00 minus the amount in the first part?"

Make sure you note that second part. The calculation gives you the answer to "How much reacted?" but the question is "How much remained?" Lots of students forget to do the second part (the 15 minus part) and so get graded down.

Note: I'm carrying a guard digit or two through the calculations. The final answers will appear with the proper number of significant figures.

**(A) Solution for limiting reagent**

1) Determine the moles of Al2S3 and H2O

aluminum sulfide: 15.00 g ÷ 150.158 g/mol = 0.099895 mol
water: 10.00 g ÷ 18.015 g/mol = 0.555093 mol

2) Divide each mole amount by equation coefficient

aluminum sulfide: 0.099895 mol ÷ 1 mol = 0.099895
water: 0.555093 mol ÷ 6 mol = 0.0925155

3) The water is the lesser amount; it is the limiting reagent.

**(B) Solution for mass of H2S formed**

Now that we know the limiting reagent is water, this problem becomes "How much H2S is produced from 10.00 g of H2O and excess aluminum sulfide?"

1) Determine moles of 10.00 g of H2O

water: 10.00 g ÷ 18.015 g/mol = 0.555093 mol

2) Use molar ratios to determine moles of H2S produced from above amount of water.

(a) the H2O/H2S ratio is 6/3, a 2/1 ratio.
(b) water is associated with the two. This means the H2S amount is one-half the water value = 0.2775465 mol.

3) Convert moles of H2S to grams.

0.2775465 mol x 34.0809 g/mol = 9.459 g

**(C) Solution for excess reagent remaining**

We will use the amount of water to calculate how much Al2S3 reacts, then subtract that amount from 15.00 g.

1) Determine moles of 10.00 g of H2O

water: 10.00 g ÷ 18.015 g/mol = 0.555093 mol

2) Use molar ratios to determine moles of Al2S3 that reacts with the above amount of water.

(a) the Al2S3/H2O ratio is 1/6
(b) water is associated with the 6. This means the Al2S3 amount is one-sixth the water value = 0.09251447 mol

3) Convert moles of Al2S3 to grams.

0.09251447 mol x 150.158 g/mol = 13.891943 g

4) However, we are not done. We were asked for the amount remaining and the answer just above is the amount which was used up, so the final step is:

15.00 g - 13.891943 g = 1.108 g

**Example #3:** If there is 35.0 grams of C6H10 and 45.0 grams of O2, how many grams of the excess reagent will remain after the reaction ceases?

2C6H10 + 17O2 ---> 12CO2 + 10H2O

**Solution:**

1) Convert each substance to moles:

C6H10: 35.0 g / 82.145 g/mol = 0.426 mol
O2: 45.0 g / 31.998 g/mol = 1.406 mol

2) Determine the limiting reagent:

C6H10: 0.426 mol / 2 = 0.213
O2: 1.406 mol / 17 = 0.083

O2 is the limiting reagent.

Comment: the units don't matter in this step. What we are looking for is the smallest number after carrying out the divisions. The 0.083 is the important thing. Not if it has a unit attached to it or not.

3) Determine how many moles of the excess reagent is used up when the limiting reagent is fully consumed:

the mole ratio we desire is 2/17 (C6H10 to O2)

2/17 equals x / 1.406

x = 0.1654 mol of C6H10 consumed

4) Determine grams of C6H10 remaining:

0.426 mol minus 0.1654 mol = 0.2606 mol of C6H10 remaining

0.2606 mol times 82.145 g/mol = 21.4 g remaining (to three sig figs)

**Example #4:** (a) What mass of Al2O3 can be produced from the reaction of 10.0 g of Al and 19.0 g of O3? (b) How much of the excess reagent remains unreacted?

**Solution to a:**

1) Write balanced chemical equation:

2Al + O3 ---> Al2O3

2) Convert grams to moles:

Al ---> 10.0 g / 26.982 g/mol = 0.37062 mol
O3 ---> 19.0 g / 47.997 g/mol = 0.39586 mol

3) Determine limiting reagent:

Al ---> 0.37062 / 2 = 0.18531
O3 ---> 0.39586 / 1 = 0.39586

Al is the limiting reagent

4) Determine moles of product formed:

Al to Al2O3 molar ratio is 2 to 1.

2 is to 1 as 0.37062 mol is to x

x = 0.18531 mol

5) Determine grams of product:

0.18531 mol times 101.961 g/mol = 18.8944 g

To three sig figs, 18.9 g

**Solution to b:**

1) Determine moles of ozone that reacted:

Al to O3 molar ratio is 2 to 1

2 is to 1 as 0.37062 mol is to x

x = 0.18531 mol

2) Determine moles of ozone remaining:

0.39586 mol - 0.18531 mol = 0.21055 mol

3) Determine grams of ozone remaining:

0.21055 mol times 47.997 g/mol = 10.1 g (to three sig figs)

**Example #5:** Based on the balanced equation:

C4H8 + 6O2 ---> 4CO2 + 4H2O

Calculate the number of excess reagent units remaining when 28 C4H8 molecules and 228 O2 molecules react?

**Solution:**

Remember, numbers are just like moles, so treating the 28 and 228 as moles is perfectly acceptable.

1) Determine the limiting reagent:

butane: 28 / 1 = 28
oxygen: 228 / 6 = 38

Butane is the limiting reagent.

2) Determine how much oxygen reacts with 28 C4H8 molecules:

the butane:oxygen molar ratio is 1:6

28 x 6 = 168 oxygen molecules react

3) Determine excess oxygen:

228 - 168 = 60

Here's aother way to consider this:

The 38 above means that there are 38 "groupings" of six oxygen molecules.

38 minus 28 = 10 oxygen "groupings" remain after the butane is used up

10 x 6 = 60