# Chapter 7 STOICHIOMETRY, Part 1



We continue the quantitative features of reactions.

In the last Chapter, our quantitative aspects were based on balance and the conservation of atoms. This was based on a simple counting of the atoms in the various chemical units which were on the left and on the right of the chemical equation.

But, alas, when it comes time to actually do a reaction, we can't count the number of atoms or of molecules or of formula units. They're too tiny and there're too many. Remember? What good is an equation based on a count if we can't do a count?

No, we cannot count actual atoms or chemical units directly but, as I told you in the beginning of Chapter 5, we can measure how many. In that Chapter, we used the mass and molar mass to measure how many formula units were in a sample. We will do so again in this Chapter. Later in Chapter 9, we will see how volume also can measure a number of formula units. In Chapter 16 when we talk about gases, we will even see how pressure can be used.

Since mass and volume are measurable things, they can provide the necessary connection to the number of formula units in a real sample. Then, when it comes time to do a reaction with some number of formula units, we can calculate the mass or the volume which is needed to provide the desired number for each reactant. We can also calculate the mass or volume for each product in the process. These mass and/or volume relationships between the reactants and products of a reaction are called "stoichiometry".

I'm going to briefly return to the notion of cooking as a follow-up on its mention in Chapter 5. Many people have at least attempted to cook something and they at least know what a recipe is. There are several parallels to note between cooking and chemical reactions.

First, both the recipe and the chemical equation relate what goes in and what comes out.

Second, the recipe gives measurable masses (e.g., oz, lb) and volumes (e.g., tsp, tbsp, c) directly for all ingredients. This part is not true for the chemical equation. The balanced chemical equation gives all reagents on a numbers-of-particles basis, but we can't use this directly. Stoichiometry takes this information and transforms it into measurables such as mass (e.g., g) and volume (e.g., L). In other words, the combination of {balanced equation + stoichiometry} is equivalent to the recipe.

When you cook and when you do a chemical reaction, you want to know how much you want to make and you want to know how much of each ingredient or reactant to throw into the pot. And you need to know this in terms of something measurable, not just numbers of particles. You also need to know how to adjust the recipe. If the recipe is for 48 brownies and you need 82, then you need to change the amounts of the ingredients. How would you calculate the amount of ingredients for 82 brownies? (OK, OK, I know what some of you are thinking. Double the recipe and eat 14 by yourself. That's not fair.)

There is one more difference between a recipe and a chemical equation: the recipe usually comes with directions. When we actually do chemical reactions in the laboratory, we do follow directions or, like some cooking, we make them up as we go. Needless to say, one has to be very careful with that. The consequences of a screw-up in a laboratory can be far more dire than a screw-up in a kitchen. Let's just say that I've used a fire extinguisher. Several times, actually.

## 7.1 We begin stoichiometry with mass.

Let's start with a basic example: we will consider the reaction of elemental hydrogen and elemental chlorine to produce hydrogen chloride. All of these are gases. All are diatomic molecules with covalent bonding. The balanced equation is the following.

$$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$$

From Chapter 6, the balanced equation relates the numbers of the chemical units involved.

| $H_2$ | + | $Cl_2$ | → | 2 HCl |
|---|---|---|---|---|
| one molecule of hydrogen, $H_2$ | reacts with | one molecule of chlorine, $Cl_2$ | to produce | two molecules of hydrogen chloride, HCl |

We can also say the following.

| $H_2$ | + | $Cl_2$ | → | 2 HCl |
|---|---|---|---|---|
| one mole of hydrogen, $H_2$ | reacts with | one mole of chlorine, $Cl_2$ | to produce | two moles of hydrogen chloride, HCl |

Remember from Chapter 5 that whenever I say a mole of some compound, I mean a mole of formula units of that compound. Everything here is composed of diatomic molecules so all the formula units are the molecular units.

| $H_2$ | + | $Cl_2$ | → | 2 HCl |
|---|---|---|---|---|
| one mole of hydrogen, $H_2$, molecules | reacts with | one mole of chlorine, $Cl_2$, molecules | to produce | two moles of hydrogen chloride, HCl, molecules |

Now, let's bring in the molar masses for each reagent. What's the mass of one mol of $H_2$ molecules? Of $Cl_2$ molecules? Of HCl molecules? The molar masses are 2.016 g, 70.90 g and 36.46 g. Put these in. Don't forget that you're dealing with two moles of HCl in the equation.

| $H_2$ | + | $Cl_2$ | → | 2 HCl |
|---|---|---|---|---|
| 2.016 g $H_2$ | reacts with | 70.90 g $Cl_2$ | to produce | 2 × 36.46 g HCl = 72.92 g HCl |

Notice that the masses of the reactants, 2.016 g $H_2$ and 70.90 g $Cl_2$, add up to 72.92 g, which is the mass of the products. This is a direct consequence of the conservation of mass: a properly balanced chemical equation will always reflect the conservation of atoms, which is the same as the conservation of matter and the conservation of mass.

These numbers (2.016 g $H_2$, 70.90 g $Cl_2$ and 72.92 g HCl) are the "recipe amounts": they are the masses for the reagents in the balanced equation as given. If you want to make 72.92 g HCl, it will take 2.016 g $H_2$ and 70.90 g $Cl_2$ (and not a smidgeon more or less). This is the simplest stoichiometry set-up. Unfortunately, life's not always simple. You have to be able to adjust the recipe. To any amount. For any reactant or product. What if you have 4.032 g $H_2$ to react? Well, that's just a doubling of the recipe. You double the $Cl_2$ (141.8 g) and then you can make double the HCl (145.8 g). What if you want to react 35.45 g $Cl_2$? That's one-half the recipe amounts. You will need 1.008 g $H_2$ and you can make 36.46 g HCl.

What if you want to react 24.77 g $H_2$? How much $Cl_2$ do you need? How much HCl can be made? OK, that's not so simple.

Before I show you how to do that, I want you to think about how you actually go about adjusting a recipe. What calculation goes through your head? Can you visualize your calculation? Could you write it down to show somebody?

Whether you are consciously aware of it or not, the calculations amount to a ratio between the desired amount of ingredient (or product) and the recipe amount. Let's consider A and B as some ingredient or product of a recipe. The calculation ratios are

$$\frac{\text{desired amount of A}}{\text{recipe amount of A}} = \frac{\text{desired amount of B}}{\text{recipe amount of B}}$$

Some people use an alternate form.

$$\frac{\text{desired amount of A}}{\text{desired amount of B}} = \frac{\text{recipe amount of A}}{\text{recipe amount of B}}$$

They're equal by rearrangement, so I'll stick with the first set.

Go back to the brownies example earlier. Let's say that the recipe calls for 1½ c flour for 48 brownies, but you need 82 brownies. How much flour do you need for 82 brownies? You could do the calculation based on the following ratios.

$$\frac{\text{82 brownies}}{\text{48 brownies}} = \frac{\text{desired amount of flour}}{1\tfrac{1}{2}\text{ c flour}}$$

This gives an answer of "2.5625" c flour which is {2 c + ½ c + 1 tbsp} flour. But who's that picky in a kitchen?

OK, now let's return to the reaction using the 24.77 g $H_2$. How much $Cl_2$ do you need? How much HCl can be made? I'll start with the $Cl_2$ part.

We can handle this in a manner similar to the recipe approach. We need our ratios.

$$\frac{\text{desired amount of } H_2}{\text{recipe amount of } H_2} = \frac{\text{desired amount of } Cl_2}{\text{recipe amount of } Cl_2}$$

The recipe amounts are those corresponding to what is given by the balanced equation directly.

$$\frac{\text{desired amount of } H_2}{2.016 \text{ g } H_2} = \frac{\text{desired amount of } Cl_2}{70.90 \text{ g } Cl_2}$$

We desire to use 24.77 g $H_2$.

$$\frac{24.77 \text{ g } H_2}{2.016 \text{ g } H_2} = \frac{\text{desired amount of } Cl_2}{70.90 \text{ g } Cl_2}$$

Take your calculator, plug in the numbers and punch out the answer. Round off to the correct sigfigs and you get 871.1 g $Cl_2$ for the desired amount. That means, in order to do this reaction with 24.77 g $H_2$, you need 871.1 g $Cl_2$. No more, no less.

Now go to the HCl part. Calculate how much HCl can be made. Set up those ratios.

$$\frac{24.77 \text{ g } H_2}{2.016 \text{ g } H_2} = \frac{\text{desired amount of HCl}}{72.92 \text{ g HCl}}$$

Plug it in, punch it out, round it off. The answer is 895.9 g HCl.

In summary, 24.77 g $H_2$ would react with 871.1 g $Cl_2$ in order to make 895.9 g HCl.

We didn't really need to do ratios for HCl. We could have used the conservation of mass. The reactant masses of 24.77 g and 871.1 g add to 895.9 g, just as calculated by the ratios. Unfortunately, this addition works when there's only one product, so this method is very limited.

Be sure to understand what we just did. Beginning with the balanced chemical equation, we determined the "recipe amounts" for each reagent. The recipe amounts were the masses for the moles of each reagent as given by the balanced equation; in other words, the molar mass times the coefficient in the balanced equation. We then adjusted the recipe for the actual amount we wanted.

## 7.2 Using dimensional analysis

Another way of doing stoichiometry calculations is with dimensional analysis. This incorporates all the separate steps above, although in a different manner. The two methods are mathematically identical, which means they're both right and they'll both give you the right answer. They're two different tools in the toolbox. When I'm working on my car and I have to remove some hex bolt, sometimes I use a closed-end wrench, sometimes I use a socket and sometimes I use an adjustable. Sometimes one works better than the other. Sometimes it really doesn't matter. (And when you're under the hood and it's a hot day and you ran the engine until it got up to temperature and your arm is wedged in front of the engine block right next to the exhaust manifold and you can't see because it's so crowded and because they-don't-make-cars-like-they-used-to, then you just may not care what tool is in your hand.) Regardless, it is very useful to have different tools for different uses.

We'll redo the same two problems as above with the 24.77 g $H_2$, now using dimensional analysis. We will calculate how many grams chlorine we need and how many grams hydrogen chloride we can make. Dimensional analysis can appear confusing at first to students because it strings all steps together. I'll break it down so that we can see what's going on.

First question: how many grams of $Cl_2$ are needed to react with 24.77 g $H_2$?

Keep in mind that we're starting over here. We're not setting up the mass relationships between all the reagents like we did in the recipe method. Dimensional analysis does not use mass relationships directly. Instead, it uses <u>mole</u> relationships directly. The masses are then derived from those. The mole relationships are the coefficients of the balanced equation. These become conversion factors. Go back to the original equation.

$$H_2 + Cl_2 \rightarrow 2 \text{ HCl}$$

If it's easier to follow, you can show the ones.

$$1\ H_2 + 1\ Cl_2 \rightarrow 2\ HCl$$

Just focus on the $H_2/Cl_2$ relationship since that is the part of the problem which we are dealing with right now. The equation says that one mole of $H_2$ reacts for every one mole of $Cl_2$ or, versa vice, one mole of $Cl_2$ reacts per one mole of $H_2$. These statements provide conversion factors which are then available for use in dimensional analysis.

$$\frac{1\text{ mol }H_2}{1\text{ mol }Cl_2} \quad \text{OR} \quad \frac{1\text{ mol }Cl_2}{1\text{ mol }H_2}$$

Now we have mole-to-mole conversion factors. These conversion factors go by different names. I like to call them "reaction ratios" but your instructor might call them something else. I will also tell you that chemists commonly abbreviate the word "reaction" as "rxn". This abbreviation is very general. I'm pointing this out now so that I can call these conversion factors "rxn ratios".

In dimensional analysis, the rxn ratios relate the numbers of formula units between the different reagents in a balanced chemical equation. Mass relationships are still done our usual way, by molar mass. For $H_2$ we have

$$\frac{2.016\text{ g }H_2}{\text{mol }H_2} \quad \text{OR} \quad \frac{\text{mol }H_2}{2.016\text{ g }H_2}$$

and for $Cl_2$ we have

$$\frac{70.90\text{ g }Cl_2}{\text{mol }Cl_2} \quad \text{OR} \quad \frac{\text{mol }Cl_2}{70.90\text{ g }Cl_2}$$

These are now all of our conversion factors related to $H_2$ and $Cl_2$. The question asks for g $Cl_2$, beginning with a given amount of $H_2$ (24.77 g). The chemical equation links $H_2$ and $Cl_2$ but that link is in moles, so the first thing to do is to go to moles: convert 24.77 g $H_2$ to mol $H_2$. Use the correct molar mass conversion factor from those shown above.

$$24.77\text{ g }H_2 \times \frac{\text{mol }H_2}{2.016\text{ g }H_2} = 12.29\text{ mol }H_2$$

This tells us that 24.77 g $H_2$ corresponds to 12.29 mol $H_2$. By the way, feel free to scratch out the units which are cancelling as we go. Next, use the rxn ratio from the balanced equation to relate mol $H_2$ to mol $Cl_2$. Use the correct conversion factor from those shown above for the rxn ratio.

$$12.29\text{ mol }H_2 \times \frac{1\text{ mol }Cl_2}{1\text{ mol }H_2} = 12.29\text{ mol }Cl_2$$

This tells us that the original 24.77 g $H_2$ will react with 12.29 mol $Cl_2$. We still need the answer in grams. Bring in chlorine's molar mass, using the correct conversion factor from the two above.

$$12.29\text{ mol }Cl_2 \times \frac{70.90\text{ g }Cl_2}{\text{mol }Cl_2} = 871.4\text{ g }Cl_2$$

This final answer tells us that the original 24.77 g $H_2$ will react with 871.4 g $Cl_2$. That's what we wanted to know. Compare this answer to 871.1 g $Cl_2$ from the recipe method: they're a tad off, and I'll come back to this point in a minute or so.

Dimensional analysis actually prefers to keep multiplication/division steps in one big string. I'll illustrate this with the part we've just finished. First, we'll plot an overall path of units from the separate steps above. We started with g $H_2$.

g $H_2$

• Then we went to mol $H_2$ using its molar mass.

g $H_2$ → mol $H_2$

• Then we related mol $H_2$ to mol $Cl_2$ by the rxn ratio.

g $H_2$ → mol $H_2$ → mol $Cl_2$

• And then we converted to g $Cl_2$ using its molar mass. This gives the full path.

g $H_2$ → mol $H_2$ → mol $Cl_2$ → g $Cl_2$

• For the full path, string out all the conversion factors.

path: g $H_2$ → mol $H_2$ → mol $Cl_2$ → g $Cl_2$

$$24.77\text{ g }H_2 \times \frac{\text{mol }H_2}{2.016\text{ g }H_2} \times \frac{\text{mol }Cl_2}{\text{mol }H_2} \times \frac{70.90\text{ g }Cl_2}{\text{mol }Cl_2} = 871.1\text{ g }Cl_2$$

If you scratch out the cancelled units, you'll see that only one remains: g $Cl_2$.

That's how a dimensional analysis string looks for stoichiometry. As you can see, these can be long. It can help to plot your path beforehand, working with just the units. This keeps track of which unit remains at each step and it can help to decide which conversion is next.

Let's summarize. The recipe method says we need 871.1 g $Cl_2$ for the reaction of 24.77 g $H_2$. Our individual steps above gave us 871.4 g $Cl_2$. The long string gave us 871.1 g $Cl_2$. Why the different numbers? The screwball is the 871.4 g. It was obtained because we rounded off after each step and we weren't supposed to. Remember what I said in Chapter 1 about round-off errors.

❝ Be sure to round-off at the end of the string of operations and not in the middle. ❞

Does that make 871.4 g wrong? It's flawed. Whoever's grading your exam decides how wrong it is. This is a frequent problem with doing steps separately. The long strings are better because they avoid round-off errors.

OK, let's do the second question of the original problem. How many grams of HCl can be made using 24.77 g $H_2$? I will do this as another string. Plot your units path. It follows similarly to the one above. We start again with g $H_2$.

g $H_2$

• Then go to mol $H_2$ using its molar mass.

g $H_2$ → mol $H_2$

Molar mass gives $\frac{2.016\text{ g }H_2}{\text{mol }H_2}$ OR $\frac{\text{mol }H_2}{2.016\text{ g }H_2}$

These are the same as earlier. You will use the one on the right in order to cancel g $H_2$ and leave mol $H_2$.

• Relate mol $H_2$ to mol HCl by the rxn ratio.

g $H_2$ → mol $H_2$ → mol HCl

Rxn ratio gives $\frac{1\text{ mol }H_2}{2\text{ mol HCl}}$ OR $\frac{2\text{ mol HCl}}{1\text{ mol }H_2}$

Notice that the rxn ratios are based on 2 mol HCl per 1 mol $H_2$ as dictated by the coefficients in the balanced equation. You will use the one on the right in order to cancel mol $H_2$ and leave mol HCl.

• Now we convert to g HCl using its molar mass.

g $H_2$ → mol $H_2$ → mol HCl → g HCl

Molar mass gives $\frac{36.46\text{ g HCl}}{\text{mol HCl}}$ OR $\frac{\text{mol HCl}}{36.46\text{ g HCl}}$

You will use the one on the left in order to cancel mol HCl and leave g HCl, which is the final unit requested by the problem.

The path is complete. Now string out all the numbers.

path: g $H_2$ → mol $H_2$ → mol HCl → g HCl

$$24.77\text{ g }H_2 \times \frac{\text{mol }H_2}{2.016\text{ g }H_2} \times \frac{2\text{ mol HCl}}{1\text{ mol }H_2} \times \frac{36.46\text{ g HCl}}{\text{mol HCl}} = 895.9\text{ g HCl}$$

You get 895.9 g HCl, just as we had obtained from the recipe method.

To summarize so far, we used the given amount of $H_2$ to calculate the amount of $Cl_2$ which we needed. We found that 24.77 g of hydrogen molecules will react with 871.1 g chlorine molecules. We also used the amount of $H_2$ to calculate the amount of HCl which can be made. We found that 24.77 g of hydrogen molecules can make 895.9 g hydrogen chloride molecules. No more, no less.

As you can see by comparing the dimensional analysis and the recipe methods, the answers are the same. The two methods are arithmetically equal but they utilize different approaches. Which one should you use? The recipe method is straightforward when given grams of one reagent and you are asked for grams of another reagent. If other units are involved, however, then the recipe method can quickly lose its simplicity. On the other hand, although perhaps tedious at first, many students find dimensional analysis better in the long run. Use whichever one you like better. Or, if your instructor requires things a certain way, then follow that way. I favor the dimensional analysis method because it is also more versatile with other kinds of problems. This is the method I will be using in this text. Keep in mind that there are variations on these methods. Your instructor or other sources may use one of the variations.

### 7.3 General approach

Since the dimensional analysis method can take some getting used to, I'll give you some steps to follow for your general, typical, everyday, average stoichiometry problem. These are pretty routine: you start with some given amount of one reagent and you need to know the amount of another reagent. The units can vary; our units so far have only been grams, but don't forget we're going to be doing volumes also. That means liters later. We can also throw in mg, kg, etc., which requires an extra conversion into g. Don't forget your powers-of-ten prefixes from Chapter 1. Another twist is to throw in an English unit, like pounds instead of grams. That means you'll have to do an English-metric conversion. Some problems can require density as a conversion step; we'll get to this in Chapter 9. Regardless of these, the basic stoichiometry part will still be pretty much the same. Here are the steps.

- Step 1. Balance the equation.
  THIS APPLIES TO ALL METHODS.
  YOU MUST HAVE A BALANCED EQUATION FOR ALL STOICHIOMETRY.
- Step 2. Convert the given unit of the given reagent to moles.
- Step 3. Convert these moles of the given reagent to the moles of the desired reagent using the rxn ratio.
  THE RXN RATIO COMES FROM THE BALANCED EQUATION. This is why you need Step 1.
- Step 4. Convert the moles of the desired reagent to the desired units.

Here's a tip. Anytime you have to go g → mol or mol → g, that's molar mass. Like I told you in Chapter 5, this must become automatic for you. This is a gimme; get this part down. Rxn ratio must also become automatic. It's how to connect <u>moles of some reagent to moles of whatever reagent</u>. It's right there in the balanced equation. Steps 2 - 4 involve your conversion factors. Be sure to know which ones are available. Remember that conversion factors come in pairs, right-side-up and upside-down. <u>Be sure to pick the correct one of each pair to put into the string.</u> The one you want is the one that cancels a prior unit and leaves you in the direction you need to be heading.

Go back to the two calculations we did for the $H_2/Cl_2$ example. Compare what we did at that time to these Steps 1 - 4. Step 1, the balanced equation, was given. Step 2 was done using the molar mass of $H_2$. Step 3 used the rxn ratio. Step 4 used the molar mass of $Cl_2$ or HCl. These steps are your basics. Know them. Understand them. If you're fuzzy on what they're doing, go back to the problem which I broke into separate steps and study the sequence.

As a new Example, I'll give you one more variation on the $H_2/Cl_2$ reaction but I'm going to give it to you all at once for you to work through. For the second question of the problem above when we calculated the amount of HCl, we based it on the 24.77 g $H_2$ which reacted. We could also have calculated the amount of HCl based on the amount of $Cl_2$.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Example 1.** For the $H_2/Cl_2$ reaction, calculate the amount of HCl which can be produced starting with 871.1 g $Cl_2$.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Here's the full path. Below that, fill in everything that is needed.

path: g $Cl_2$ → mol $Cl_2$ → mol HCl → g HCl

871.1 g $Cl_2$ × ―――――― × ―――――― × ―――――― = ____________ g HCl

Plug it in, punch it out and round it off. Compare your answer to the one found before.

Right now it may be about time for a brain break. Make sure it's temporary. Go get a cup of water or coffee or tea or sarsaparilla or something. Whatever. When you're done, come back here. I'll be waiting.

* * * * * * * * * * *

Let's do a different Example, completely from scratch.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Example 2.** Consider the reaction of titanium(IV) chloride with water to produce titanium(IV) oxide and hydrogen chloride. How many grams of titanium(IV) chloride are needed in order to make 325 g titanium(IV) oxide?

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 

OK, this one's a bit tedious. Where to start? As has been said, "It's always best to start at the beginning."

Stoichiometry Step 1 says we need a balanced equation. To get there, we first need some formulas. Titanium(IV) chloride is $TiCl_4$. Water is good old $H_2O$. Titanium(IV) oxide is $TiO_2$. Hydrogen chloride is HCl. $TiO_2$ is the white pigment which I mentioned at the end of Chapter 4. That stuff is used all over the place these days.

OK, we need a balanced equation. Line 'em up.

(unbalanced) $\_\ TiCl_4 + \_\ H_2O \rightarrow \_\ TiO_2 + \_\ HCl$

Now fix it. You have four reagents and four coefficients.

‣ Ti: There's one Ti on each side, as written so far; let's keep their coefficients at one.

(unbalanced) $\underline{1}\ TiCl_4 + \_\ H_2O \rightarrow \underline{1}\ TiO_2 + \_\ HCl$

‣ Cl: There're four Cl's on the left from the assigned coefficients so far. You need four Cl's on the right.

(unbalanced) $1\ TiCl_4 + \_\ H_2O \rightarrow 1\ TiO_2 + \underline{4}\ HCl$

‣ H: There're four H's on the right by the assigned coefficients so far. You need four on the left. You must use a two on $H_2O$.

$$1\ TiCl_4 + \underline{2}\ H_2O \rightarrow 1\ TiO_2 + 4\ HCl$$

‣ O: There are two O's on each side, so they're OK.

Done? ✓No fractional coefficients.
✓Coefficients are smallest whole numbers.

Fine. Stoichiometry Step 1 is done.

The problem gives the amount for one of the products, $TiO_2$, and it asks for the amount of one of the reactants, $TiCl_4$. The reaction will also use some $H_2O$ and it will also make HCl but the problem does not concern those reagents. <u>Focus only on the reagents specified</u> by the given problem. Follow the standard Steps 2 - 4. Plot your path: begin with the given amount of 325 g $TiO_2$.

g $TiO_2$

• Step 2. Molar mass will go from g $TiO_2$ to mol $TiO_2$.

g $TiO_2$ → mol $TiO_2$

Molar mass gives $\dfrac{79.87\text{ g }TiO_2}{\text{mol }TiO_2}$ OR $\dfrac{\text{mol }TiO_2}{79.87\text{ g }TiO_2}$

You will use the one on the right in order to cancel g $TiO_2$ and leave mol $TiO_2$.

• Step 3. You relate mol $TiO_2$ to mol $TiCl_4$ using the rxn ratio from the balanced equation.

g $TiO_2$ → mol $TiO_2$ → mol $TiCl_4$

Rxn ratio gives $\dfrac{1\text{ mol }TiO_2}{1\text{ mol }TiCl_4}$ OR $\dfrac{1\text{ mol }TiCl_4}{1\text{ mol }TiO_2}$

You will use the one on the right in order to cancel mol $TiO_2$ and leave mol $TiCl_4$.

• Step 4. You get from mol $TiCl_4$ to g $TiCl_4$ using molar mass. This is the target answer for the problem.

g $TiO_2$ → mol $TiO_2$ → mol $TiCl_4$ → g $TiCl_4$

Molar mass gives $\frac{189.67 \text{ g } TiCl_4}{\text{mol } TiCl_4}$ OR $\frac{\text{mol } TiCl_4}{189.67 \text{ g } TiCl_4}$

• Now string it all together.

path: g $TiO_2$ → mol $TiO_2$ → mol $TiCl_4$ → g $TiCl_4$

$$325 \text{ g } TiO_2 \times \frac{\text{mol } TiO_2}{79.87 \text{ g } TiO_2} \times \frac{1 \text{ mol } TiCl_4}{1 \text{ mol } TiO_2} \times \frac{189.67 \text{ g } TiCl_4}{\text{mol } TiCl_4}$$

Plug it in, punch it out, round it off.

$$325 \text{ g } TiO_2 \times \frac{\text{mol } TiO_2}{79.87 \text{ g } TiO_2} \times \frac{1 \text{ mol } TiCl_4}{1 \text{ mol } TiO_2} \times \frac{189.67 \text{ g } TiCl_4}{\text{mol } TiCl_4} = 772 \text{ g } TiCl_4$$

There's your answer: in order for you to make 325 g $TiO_2$, you will need to use 772 g $TiCl_4$. And again, you will need some $H_2O$ and the reaction will also make some HCl, but those amounts were not of concern for this problem.

Now let's change the problem and put you to work.

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**Example 3.** In the process of making 325 g $TiO_2$ as in the above Example 2, how many grams of HCl are also produced?

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

You need to execute the same steps as previously, but now focusing only on $TiO_2$ and HCl. The same balanced equation applies, so Stoichiometry Step 1 is done. Proceed with Steps 2 - 4. Plot your path, beginning with 325 g $TiO_2$.

g $TiO_2$

• Step 2. Molar mass will go from g $TiO_2$ to mol $TiO_2$.

g $TiO_2$ → mol $TiO_2$

As above, you have $\frac{79.87 \text{ g } TiO_2}{\text{mol } TiO_2}$ OR $\frac{\text{mol } TiO_2}{79.87 \text{ g } TiO_2}$

• Step 3. You relate mol $TiO_2$ to mol HCl using the rxn ratio from the balanced equation.

g $TiO_2$ → mol $TiO_2$ → mol HCl

Rxn ratio gives $\frac{1 \text{ mol } TiO_2}{4 \text{ mol HCl}}$ OR $\frac{4 \text{ mol HCl}}{1 \text{ mol } TiO_2}$

• Step 4. You get from mol HCl to g HCl using molar mass. This is your target for this problem.

g $TiO_2$ → mol $TiO_2$ → mol HCl → g HCl

Molar mass gives $\frac{36.46 \text{ g HCl}}{\text{mol HCl}}$ OR $\frac{\text{mol HCl}}{36.46 \text{ g HCl}}$

• Now string it all together.

g $TiO_2$ → mol $TiO_2$ → mol HCl → g HCl

325 g $TiO_2$ × ________ × ________ × ________ = ________ g HCl

Enter your conversion factors. All units should cancel except g HCl. If you have troubles, look upstairs at the prior Example 2; it's very similar. Once you've got everything lined up, plug it all in, punch it out and round it off. What did you get? I won't tell you the answer, but I'll give a clue. The answer has three sigfigs. The three digits of the answer add to 17.

This concludes our stoichiometry basics. Before ending this Chapter, I want to stress upon you that stoichiometry problems are among the most fundamentally important problems in chemistry. These are among the most common calculations we do. Before we even run a reaction in the research lab, we will do these kinds of calculations. You need to know how to do these. It will take practice. Do the practice and then do some more. Balancing equations and doing stoichiometry problems can take a while to get used to. Get help if you need to. And do it before it gets too late.

We continue the next Chapter with more aspects of stoichiometry.

**Problems**

1. The following equation is balanced.

$$SiF_4 + 2\ Ca(OH)_2 \rightarrow 2\ CaF_2 + SiO_2 + 2\ H_2O$$

If the reaction is conducted using 12.48 g $Ca(OH)_2$, how many grams of $SiF_4$ are needed?

2. The following equation is balanced.

$$O_2 + BrF_3 + 2\ K_2O \rightarrow KBrO_4 + 3\ KF$$

If the reaction is conducted using 25.68 g $BrF_3$, how many grams of $K_2O$ are needed?

3. The following equation is balanced.

$$2\ NaNO_2 + H_2O_2 \rightarrow 2\ NaOH + 2\ NO_2$$

In order to make 6.83 g $NO_2$, how many grams of $H_2O_2$ are needed?

4. The following equation is balanced.

$$P_4S_4 + 8\ Cl_2 \rightarrow 4\ PCl_3 + 2\ S_2Cl_2$$

If the reaction is conducted using 21.5 g $Cl_2$, how many grams $S_2Cl_2$ can be made?

5. The following equation is balanced.

$$BeI_2 + H_2S \rightarrow BeS + 2\ HI$$

If the reaction is conducted using 67.91 g of $BeI_2$, how many grams of HI can be made?

6. Acetylene, $C_2H_2$, is used in welding applications. How many grams of $O_2$ are needed for the combustion of 12.50 g $C_2H_2$?

7. The reaction of oxygen and copper(I) sulfide produces copper(II) oxide and sulfur dioxide. How many grams of oxygen are necessary in order to make 17.6 g copper(II) oxide according to this reaction?

8. The combustion of ethylene, $C_2H_4$, yields carbon dioxide and water. The carbon dioxide formed in this combustion can then react completely in a second step with calcium oxide to form calcium carbonate. How many grams of calcium carbonate can be made in this manner using 27.2 g $C_2H_4$?