Determining the Coefficients of a Balanced Chemical Equation by Experiment

Experiment 1

The Reaction of a Metal with a Strong Acid

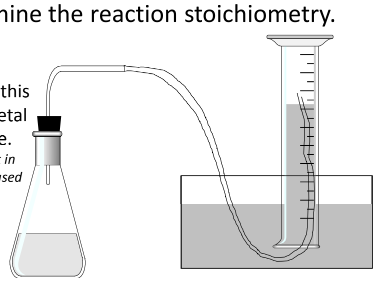
A number of metals will react with a strong acid {such as HCl(aq)} via a single displacement reaction to form hydrogen gas.

$$a\ \text{“M”}(s) + b\ HCl(aq) \rightarrow (^{b}/_{2})\ H_2(g) + a\ MCl_x(aq)$$

Because this reaction produces a gas, the progress of the reaction can be monitored by measuring the amount of gas that is generated. This provides a convenient way to explore the stoichiometry of the reaction and determine the values of "a", "b", and "x" in the above chemical equation.

By systematically varying the amount of one of the reactants while keeping the other constant over a series of runs, the volume of gas produced can be monitored and the trends observed in the data can be used to determine the reaction stoichiometry.

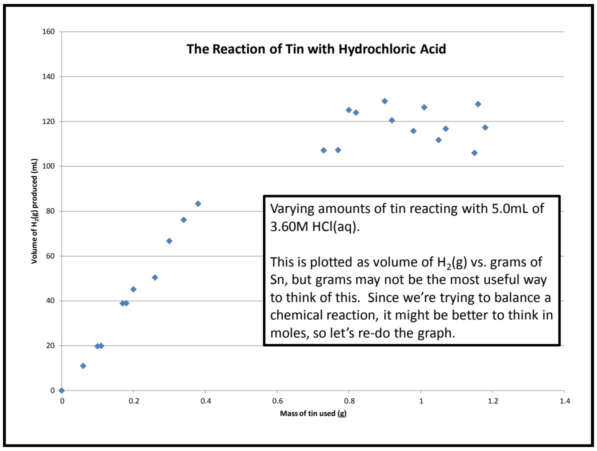
Let's look at some representative data for this experiment using tin metal as a theoretical example.
Note, tin may not actually work in this experiment, it's just being used as an example here.



We can either vary the amount of tin or the amount of acid in this experiment, let's say we're going to vary the amount of tin and we generate the following graph.

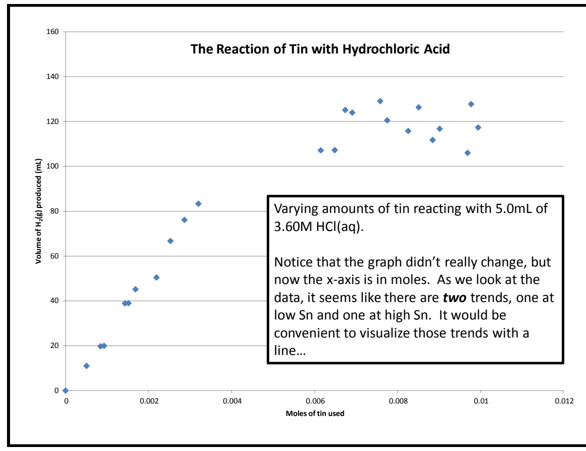
For this experiment, we are using 3.60M hydrochloric acid and since we are keeping this constant we'll use 5.0mL of the acid in each run.

The data looks like…



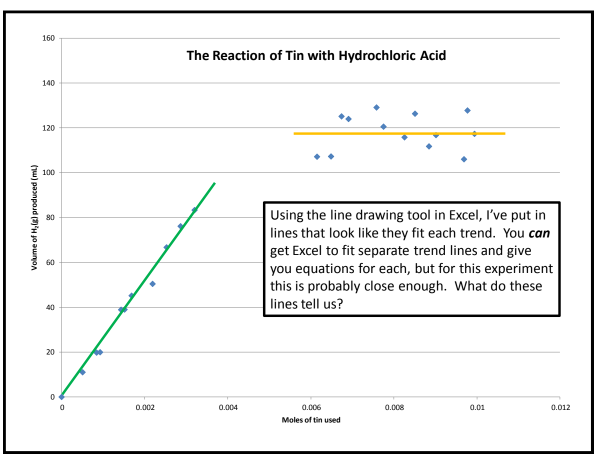
Varying amounts of tin reacting with 5.0mL of 3.60M HCl(aq).

This is plotted as volume of H_2(g) vs. grams of Sn, but grams may not be the most useful way to think of this. Since we're trying to balance a chemical reaction, it might be better to think in moles, so let's re-do the graph.

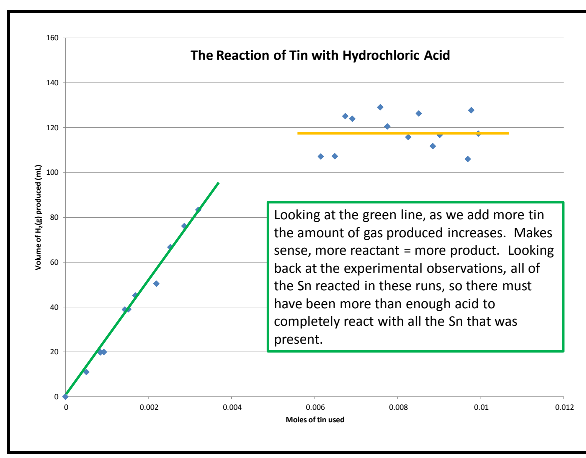


Varying amounts of tin reacting with 5.0mL of 3.60M HCl(aq).

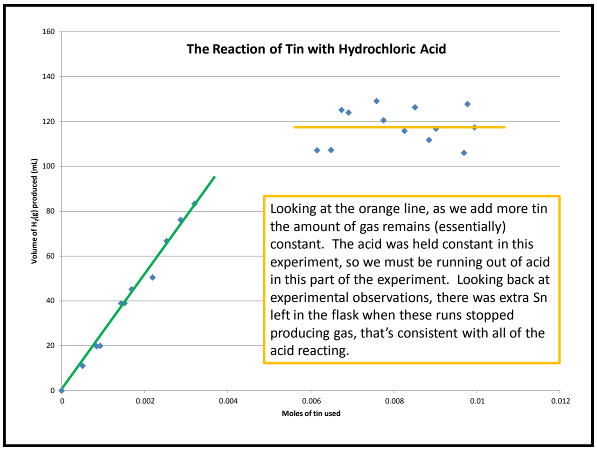
Notice that the graph didn't really change, but now the x-axis is in moles. As we look at the data, it seems like there are ***two*** trends, one at low Sn and one at high Sn. It would be convenient to visualize those trends with a line…

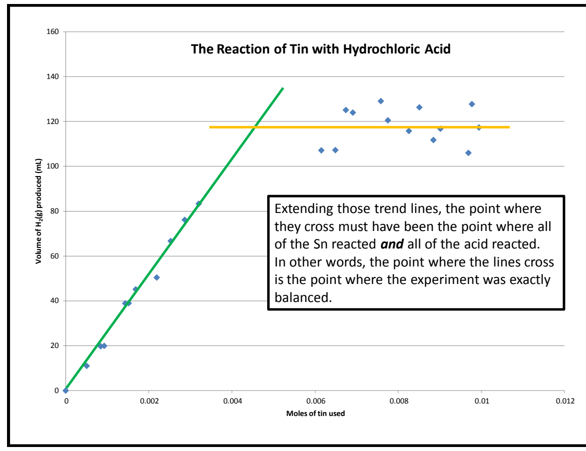


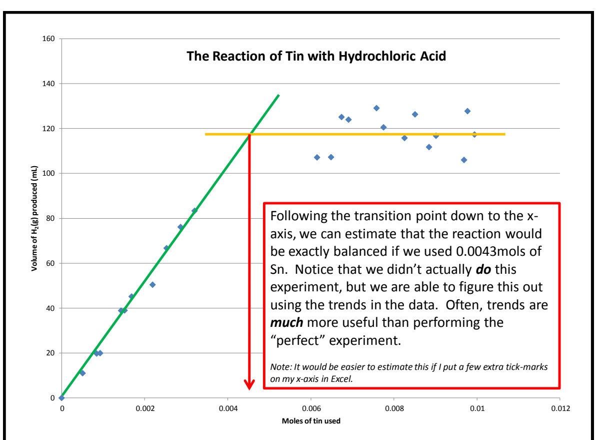
Using the line drawing tool in Excel, I've put in lines that look like they fit each trend. You ***can*** get Excel to fit separate trend lines and give you equations for each, but for this experiment this is probably close enough. What do these lines tell us?



Looking at the green line, as we add more tin the amount of gas produced increases. Makes sense, more reactant = more product. Looking back at the experimental observations, all of the Sn reacted in these runs, so there must have been more than enough acid to completely react with all the Sn that was present.







OK, now we have some numbers with which to **experimentally** balance our equation. 0.0043mols of Sn react with 5.0mL of 3.60M HCl(aq).

$(0.0050\text{L})(3.60\ ^{\text{mols HCl}}/_{\text{L}}) = 0.018\text{mols HCl(aq)}$

Looking back at the equation:

a Sn(s) + b HCl(aq) → $(^{b}/_{2})$ H_2(g) + a $SnCl_x$(aq)

we'd like to get those moles to whole numbers, so simplify that ratio:

0.0043:0.018 → 1:4.2

That is the mole ratio ("a" and "b" in the equation) that you have **experimentally** determined.

Plugging in to the equation:

$1\ Sn(s) + 4.2\ HCl(aq) \rightarrow 2.1\ H_2(g) + 1\ SnCl_x(aq)$

What about that "x"? In a perfect and theoretical world, we'd like that to be a whole number (and we'd also like the "4.2" and "2.1" to be whole numbers), but this is **experimentally** derived ("**empirical**") data, so in this case it's probably best to report "x" as 4.2 (based upon the number of chlorides on the balanced reactant side).

$1\ Sn(s) + 4.2\ HCl(aq) \rightarrow 2.1\ H_2(g) + 1\ SnCl_{4.2}(aq)$

Based upon this **experimentally** balanced equation, we can probably estimate that the correct balanced equation *should* be:

$1\ Sn(s) + 4\ HCl(aq) \rightarrow 2\ H_2(g) + 1\ SnCl_4(aq)$

Why isn't it perfect? Because it's ***empirical***! In this case, it's pretty close, let's estimate the error with a percent error:

(error/known)*100% = percent error

(0.2/4)*100% = 5%

Not bad, I think we can live with 5% error.

The whole point of this experiment is to balance a chemical equation ***empirically***. Notice that at no time in the preceding analysis did I talk about charges or positions on the Periodic Table, or correct chemical formulas that I looked up in a book or on the internet. Base your results upon your experimental observations. If you do not do this, you will not earn many points on the hand-in.