Iowa Science Teachers Journal

Volume 37 | Number 3 Article 4

2010

A Balancing Act: Helping Students Understand the Mole Relationship for Balancing Equations

Karl Goldsmith
West Des Moines Valley High School

Matt Jaschen
Johnston High School

BALANCING ACT

Graphic Work by Joe Taylor

HELPING STUDENTS UNDERSTAND THE MOLE RELATIONSHIP FOR BALANCING EQUATIONS

Karl Goldsmith, West Des Moines Valley High School
Matt Jaschen, Johnston High School

ABSTRACT: Stoichiometry can be one of the more challenging topics to teach in high school chemistry. Students often struggle until they realize the ratio from the balanced chemical equation represents mole ratios rather than the mass of each component. The activity presented here provides students with an inquiry based experience with a chemical reaction. During the activity, students seek evidence as to what the coefficients in a balanced chemical equation mean. With teacher guidance, these activities help students (1) connect chemical equations to observations, (2) gain evidence that mass ratios are not useful, and (3) understand the relationship between moles and balanced chemical equations. *This article promotes National Science Education Standards A, B, and G, and Iowa Teaching Standards 2, 3, and 4.*

Students find stoichiometry a difficult concept to grasp in chemistry. The concept becomes clearer once students realize what the balanced chemical equation actually represents. Often, students believe the coefficients of the balanced chemical equation are related to the mass of the components. Simply telling students that the coefficients represent mole ratios does little to help students deeply understand the meaning of the coefficients. According to Clough (2002), students benefit from reflection upon hands-on experience to understand scientific concepts. These experiences should be provided as a starting point upon which teachers can guide students thinking regarding the scientific concept.

Exploring the Reaction

Before this point in our class, students have already learned to balance equations and recognize the mole concept as a useful counting mechanism. Additionally, students must be able to convert among moles, grams, and molarity before this lesson takes place. In our experience, building from balancing equations to mole conversions to the more abstract notion of how moles and chemical equations relate has typically been an effective way to scaffold students' thinking.

We start the activity with a demonstration, but you might have students do the reaction as well. A small amount of sodium carbonate is placed in a beaker, and hydrochloric acid is added with an eyedropper. Throughout the demonstration we ask questions to help students make conclusions about their observations. Asking thought provoking questions requires students to think more deeply about what they are observing (Penick, et al., 1996). These questions are used to encourage students to make predictions, explain their thinking, and make connections to prior learning. Some questions we ask during the investigation include:

- What do you think will happen when I add the hydrochloric acid to the sodium carbonate?
- What might we see that would support your prediction?
- What type of change do you think happened in the beaker?
- What evidence do you have to support this idea?
- How do you know when the reaction has finished?
- How might a balanced chemical equation help us refine our predictions or thinking?

While these questions are meant to encourage students' active mental engagement, the questions are not enough. We are also sure to provide adequate wait time both before and after students respond and look around the room inquisitively to encourage more students to share their thinking or respond to another student's idea. We work hard to not judge the students' responses. Instead, we ask students to elaborate or explain why they think what they do. Rather than simply telling students how we might proceed, we ask them to think about how a particular action might be beneficial as is demonstrated by the last question above.

When the reaction produces a gas, the students typically note that a chemical change has taken place. We ask, "What is the gas produced from the bubbles?" Students will give a variety of answers including hydrogen, oxygen, carbon dioxide, or water vapor. If students say something like nitrogen, we ask, "From where would nitrogen have come?" Once students recognize the nitrogen atoms are not part of the reaction, they quickly dismiss the idea.

We know that a splint test works well to test for which gas is produced, but we do not want to simply tell students about this test. Instead, we ask students what they know about these gases. Depending on the class, students will note that oxygen is necessary for breathing, that hydrogen is flammable, that mammals exhale carbon dioxide and water vapor among other characteristics. When students mention something about flammability (or explosions) we use that idea to move their thinking forward. We ask, "In what ways would all of these gases interact with fire?" or in a more guiding manner we might ask, "What will happen if I put a lit splint over hydrogen? Oxygen? Carbon dioxide?" Students normally say that the flame would go out with the carbon dioxide or blow up with the hydrogen. They struggle with oxygen because they know it is essential to combustion, but easily accept that the flame burns brighter.

After performing the splint test and seeing the flame extinguish we ask,

- "We now have some evidence that carbon dioxide is produced. From where does the carbon dioxide originate?"

Students might note that the carbon dioxide comes from the reactants, but usually struggle to explain further. Here we either revisit the chemical equation if discussed previously, or ask students how trying to write the chemical equation might be useful.

When students write the chemical reaction as

$$2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2CO_3$$

we ask which of the products is the gas or how the equation fits with what they know about the reaction from the splint test. Too often students do not make connections to what they see and the equations they write. Asking targeted questions encourages them to make these important connections.

LAB SAFETY

As this activity deals with hydrochloric acid, certain safety precautions should be considered. The concentration of the acid is not crucial. We use 1 M HCl, but stronger or weaker concentrations can be used. Students should also be following the standard safety protocols such as wearing goggles at all times. It is a good idea to remind students about the location of the eye wash stations and what to do if they do spill an acid.

Students understandably struggle with reconciling the products they write and the splint test so are ready for an explanation. We explain that H_2CO_3, carbonic acid, is the correct product, but quickly breaks down into water and carbon dioxide. Accounting for this new information, the students easily modify their equation to

$$2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$$

Exploring Ratios

After students have come to understand the reaction, we ask

- "How can we measure the amounts of each reactant so the reaction reaches completion without excess materials?"

Students will typically say to use twice as much hydrochloric acid as sodium carbonate. This might seem intuitive, but probing further we ask,

- "How will you measure out the amounts of each reactant?"

Now students reveal their misconception and claim that massing out twice as much hydrochloric acid than sodium carbonate is appropriate. We want to let students test this idea, but first we need a way to determine if the reaction is actually complete at the end of our trial.

To help students devise a way to test for the presence of excess reactants we ask,

- "Assume your reaction had too much hydrochloric acid, how could you test to confirm there was too much hydrochloric acid?"

If students need some additional scaffolding we ask,

- "If there was too much hydrochloric acid and we added some more sodium carbonate, what would happen?"

Students quickly realize that the reaction would happen again and they would see fizzing. We then reverse the situation and ask,

- "Assume your reaction had too much sodium carbonate, how could you test to confirm?"

Students quickly realize they could add more hydrochloric acid. Now, because they do not know if they will have excess or which reactant will be in excess, we note that the reaction must be carried out twice.

To conserve materials we have students measure out 2 grams of hydrochloric acid and 1 gram of sodium carbonate and mix them in a test tube, then repeat these measurements and mix in a second test tube. To one test tube, the students add drops of hydrochloric acid, to the other they add a small amount sodium carbonate. When we use 1 M HCl, and use mass to measure out at 2:1 ratio of acid to carbonate, the carbonate is nearly ten times in excess. Therefore, the test tube to which the hydrochloric acid is added after the reaction continues to fizz, even after adding many drops of hydrochloric acid. We ask students what this means and they are typically able to explain that there is too much sodium carbonate. Then, we explicitly state that the ratio of coefficients in the balanced equation must not be related to mass.

Students have now proposed an idea based on a common misconception of balanced chemical equations, tested that idea, and witnessed evidence that the idea is not accurate. We now ask,

- "If the ratio in the balanced equation does not relate masses, to what might the ratio relate?"

Although students are not sure, almost every class has suggested moles. We do not simply confirm this idea; we ask students how to test it!

Students will say they need 2 moles of hydrochloric acid and 1 mole of sodium carbonate. Unfortunately, at 1 mole/liter, this would require 2 liters of acid and 83 grams of sodium carbonate! We ask students how many moles of sodium carbonate they would need if they had .02 moles of acid. The students easily note that .01 moles of sodium carbonate would be needed and we ask them to work with their partners to figure out how many grams of sodium carbonate they need and how many milliliters of acid they need. We walk around during this time fielding questions and listening in on students' conversations about the task. Based on the numbers we've used here students need .83 grams of sodium carbonate and 20 mL of 1 M hydrochloric acid.

We have students again carry out this reaction in duplicate (mixing well) and test to see if there is excess of either reactant. Some groups will claim there is excess of one or the other reactant, but if we look at the overall class data, the variation on both sides is easily understandable as errors. That is, some groups had excess acid, others had excess sodium carbonate and others had excess of both and others had no excess of either. The results of this new test support the notion that the coefficients in a balanced chemical equation represent mole ratios.

To help students reflect on this, we give them some time at the end of class to summarize the new insights in writing. If students are struggling, we might ask them to write about two specific issues:

1) How they know that the coefficients of a balanced chemical equation are not related to mass, and

2) Why using moles rather than mass is a better way to think about how reactants relate to each other in a chemical reaction.

This second question is not easy for students and provides great insight for us as we plan for subsequent lessons on chemical reactions and the mole concept.

Conclusion

Stoichiometry and chemical equations can be difficult subjects for students. Having an inquiry-based, exploratory lab at the beginning helps students make connections between moles, equation coefficients, and what they see in the reaction itself. Too often the mathematics of chemistry is taught divorced from the phenomena of chemistry. By using laboratory investigations to help students make sense of, rather than verify, the mathematical nature of chemistry, students are more likely to come to deep understandings of the concepts.

The teacher's role throughout this activity is crucial. Teachers help students make connections from what they see in lab to the science concept behind it (Penick, et. al,. 1986). While the laboratory could be conducted more efficiently, learning is not efficient. It is often quite messy! Encouraging students to express and even test their misconceptions through questioning creates the cognitive dissonance and active mental engagement necessary for true conceptual change.

References

Clough, M. (2002). Using The Laboratory To Enhance Student Learning. Chapter 8 in Bybee, Rodger W. (Ed.) *Learning Science and the Science of Learning*, 2002 NSTA Yearbook. National Science Teachers Association, Washington, D.C. pp. 85-94.

Penick, J. et al. 1986. Teachers Make Exemplary Programs. *Educational Leadership.* 44(2): 14-20.

Penick, J. et al. 1996. Questions are the Answer. *The Science Teacher*. 63(1):27-29.

Karl Goldsmith is a Chemistry teacher at West Des Moines Valley High School. He is a member of the National Science Teachers Association. Karl can be contacted at goldsmith@wdmcs.org. Matt Jaschen teaches Biology and Chemistry at Johnston High School. Matt can be contacted at matt.jaschen@johnston.k12.ia.us.