Bill’s Box

Extension of article in Oct., 2013 “The Science Teacher”

Updated: October 15, 2014

Author’s Note:
Thank you for visiting this site. All comments, suggestions and questions are welcome.
Please address them to Bill Struck at: struckwi@msu.edu

About this extension:
The article published in The Science Teacher (October, 2013) was, due to space limitations, a truncated version of the original submission. The complete version is presented here.

The strategy for teaching stoichiometry presented in The Science Teacher covered problem types 1-5 (found on p.3-8 of this article). These problems introduce simple stoichiometry concepts by using easy-to-understand analogies and then progress to a problem involving combustion of a hydrocarbon, a limiting reactant and mass-to-moles conversions. Of course teachers can substitute their own favorite analogy.

More advanced types of stoichiometry problems are found in this complete version. These examples clearly illustrate how students can easily build on their “Bill’s Box skills” as new concepts are acquired:

- aqueous solutions see problem type 6 (p.9)
- standardizing a base with KHP see problem type 7 (p.10)
- determining the equivalent weight of an unknown acid see problem type 8 (p.11)
- titrating a diprotic acid with NaOH see problem type 9 (p.12)
- ideal gases see problem type 10 (p.13)
- summative problem see problem type 11 (p.14)

Teaching tips, summary and references are found on p.15-16.

Thank you for your interest.

Bill Struck

Williamston High School (retired)
Williamston, Michigan
struckwi@msu.edu
A Simple and Effective Approach to Stoichiometry

Abstract: This article describes an effective method of teaching stoichiometry to beginning chemistry students. Students at the secondary and college levels find it helpful because the method starts with familiar analogies and a simple organizing grid. Using the approach, students quickly grasp the basic concepts of quantifying chemical reactions; from this comfortable beginning, additional and more complex relationships are easily introduced.

Article

Mastering stoichiometry is crucial for success in college chemistry

Stoichiometry first appeared over 200 years ago with the work and publications of Richter, Fischer, Dalton and Berzelius (1). Since the late 1800’s stoichiometry has consistently been a part of introductory chemistry textbooks (2). Most modern-day professors teaching undergraduate college chemistry courses emphasize stoichiometry early in their course—typically within the first three weeks. College professors also feel that high school chemistry courses need to spend more time on equations and stoichiometry concepts (3). Not surprisingly, proficiency with stoichiometry at the secondary level has been shown to be a strong predictor for success in college chemistry (4). Many incoming freshmen are not well prepared for college: 30-60% require remedial coursework and approximately 30% drop out entirely (5). Clearly the extent and methods used to teach stoichiometry in high school chemistry need to be closely examined.

A major challenge of teaching stoichiometry at both the secondary and college levels is the diversity of students’ level of cognitive understanding. Mastery of many computational chemistry skills requires higher order thinking skills. Frequently these skills are taught using algorithms of diagrams, stories, concept maps and numerous mnemonics (6-14). With rare exceptions (6,7), these methods are unrelated to the balanced chemical reactions that represent the actual chemical process. With this disconnect it is no wonder that deep conceptual understanding is often lacking. Study results vary but most show that less than half of secondary chemistry students posses what Piaget calls formal operation thinking. Instead many are only at the concrete operational thinking stage (9,15,16). With such student diversity and the ultimate need for formal operational thinking, introductory chemistry teachers would benefit from instructional methods that help a broad spectrum of students. The method presented here is such an approach.

In one class period students easily learn the basics of this single approach and later build on it throughout their study of stoichiometry. Eleven categories of questions are presented here. These questions systematically and effectively guide students to an understanding of stoichiometric concepts and help them build the skills necessary to solve related problems. Unknowns involved in chemical reactions that can be calculated using this approach include: moles, mass and volume of reactants and products, limiting reactant, excess reactant, moles and mass of excess reactant, molarity of solutions, molar mass (a.k.a. gram formula mass—gfм), gas pressure, gas temperature, the ideal gas constant and coefficients of a chemical equation. By the time students address all categories, most have a strong conceptual foundation and the necessary skills to master all of these topics.
Introduce stoichiometry with a simple analogy and an organizing grid

Many real world analogies have been successfully used to convey the concept of whole number relationships in chemical reactions: making sandwiches, s’mores, fruit baskets/salads, nuts/bolts/washers, cakes/cupcakes, coins, construction blocks, dresses and student teams (15-24). Analogies that are most familiar to students and allow for hands-on experience may be the most effective for students regardless of their cognitive level (15,21,25). Whatever analogy the instructor is most comfortable with can be substituted for the author’s analogy. First a non-chemistry question is posed to students. This form of guided inquiry has been shown to be an effective way for students to develop long-lasting conceptual understanding (26).

Problem Type 1
1) The ACME Tricycle Co. needs to plan its next production run.
2) Each tricycle is made from one frame, three wheels and two handle-bar grips.
3) Using only symbols and numbers, write an equation that represents this process.
4) How many frames, wheels and grips are needed to produce 6,000 tricycles?
5) Try to solve this without your calculator.
6) Write down your answers.

Most students will answer this very quickly. Their equation should resemble:

\[ F + 3W + 2G \rightarrow FW_3G_2. \]

Next model the construction of a 3-row organizing grid—drawn underneath the equation with one column aligned with each reactant and each product; label the bottom line “count.” Give this grid a name because it can be used to answer most stoichiometry related to chemical reactions. The author uses an alliterative easy-to-remember name: “Bill’s Box.” The starting point is identified with a star (★) and shaded green. For each part ask, “Will the count be the same, more or less?” Have different students come forward and insert their answers. When question 1 is completed, the Bill’s Box will look like Figure 1. Final answers are bolded and shaded red.

<table>
<thead>
<tr>
<th>F</th>
<th>+</th>
<th>3W</th>
<th>+</th>
<th>2G</th>
<th>\rightarrow</th>
<th>FW_3G_2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>count</td>
<td>6,000</td>
<td>18,000</td>
<td>12,000</td>
<td>6,000★</td>
<td>(starting point)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Completed grid after answering problem type 1.

Using the coefficients, calculations along the bottom line relate the desired tricycle count to counts for grips, wheels and frames. This is of course analogous to calculating mole-to-mole relationships. Using the term “bottom line” is appropriate because mole-to-mole calculations guided by the coefficients of a balanced chemical equation are fundamental to stoichiometry.
Reinforce concepts with another analogy

To help students become more comfortable calculating count-to-count relationships in all directions, ask another question.

Problem Type 2

1) The ACME Tricycle Co. discovers it has 24,000 grips in stock.
2) How many frames and wheels are needed to use up all these grips?
3) How many tricycles can be produced?
4) Re-write the equation, construct Bill’s Box and record your answers in the appropriate box.

Again model: start by writing the equation, draw the Bill’s Box, identify the starting point with green shading and a star and then use arrows to point where answers are needed. For each reactant/product, again ask “Will the count be the same, more or less?” Have students come forward and insert their answers. The bold numbers shaded red in figure 2 represent these final answers.

\[ \text{F} + 3 \text{W} + 2 \text{G} \rightarrow \text{FW}_3\text{G}_2 \]

<table>
<thead>
<tr>
<th>count</th>
<th>12,000</th>
<th>36,000</th>
<th>24,000</th>
<th>12,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. Completed grid after answering problem type 2.

Problem types 1 and 2 lay the foundation for all subsequent stoichiometry problems. Additional practice is essential. Using a variety of analogies, especially ones with hands-on experience, may be particularly effective (16,17,18,24).
Progress to count calculations & limiting reactants

The next closely related analogy introduces two concepts: 1) limiting reactant and 2) calculating counts from packaged quantities. Students are presented with a problem that they cannot solve until they are given conversion information. This creates a conflict that pushes them to higher order problem solving (16).

Problem Type 3
1) The ACME Tricycle Co. has an inventory of parts.
2) The inventory is: 27 cases of frames, 12 boxes of wheels and 42 kg of grips.
3) How many tricycles can be made? What part will they run out of first?
4) Begin by writing the equation & constructing Bill’s Box.

Give students plenty of time to struggle with this question; after some time ask what would help them solve the problem. While they are doing that, construct Bill’s Box with the addition of the packed amounts in the top line—labeled “amount.” What’s needed of course is the number of frames/case (12), wheels/box (100) and grips/kg (15). Supply these values one at a time—logically each under the appropriate amount; as each conversion factor is revealed, enter it on the middle line-labeled “conversion information.” Sequentially ask all students to calculate the count of each part and then calculate the number of tricycles that could be made with that part (three answers). Most students intuitively know the smallest number of tricycles identifies the limiting reactant (in this case: grips). Clarify terms: limiting reactant and reactants in excess. Identify all 3 starting points (★), use arrows to point where answers are needed, identify the limiting reactant (★) and circle the number of tricycles that can be made with the existing inventory. Italicized numbers represent intermediate answers and bold numbers shaded red represent final answers. By the time question three is completed, Bill’s Box will look like figure 3.

<table>
<thead>
<tr>
<th>amount</th>
<th>27 cases ★</th>
<th>12 boxes ★</th>
<th>42 kg ★</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>12 frames/case</td>
<td>100 wheels/box</td>
<td>15 grips/kg</td>
</tr>
<tr>
<td>count</td>
<td>324</td>
<td>1,200</td>
<td>630 ★</td>
</tr>
</tbody>
</table>

Figure 3. Completed grid after answering problem type 3.
Apply the concepts to moles, mass and Law of Conservation of Mass

The proportionality expressed by coefficients can reflect a literal count or any numeric ratio: dozen-to-dozen, gross-to-gross or of course a ratio of moles. Up to this point the term “mole” has not even been used. There are many ways to introduce the mole concept (8,11,13,27-30). A significant advantage gained by using the previously outlined sequence of analogies, Bill’s Box and conversion information is that by now most students fully grasp the concept that reactant/product ratios reflect numeric ratios NOT mass or volume ratios. Once the mole and molar mass (gfm) concepts are introduced to students, the Bill’s Box method can be readily applied to other stoichiometric concepts and problems.

Problem Type 4
1) 23.45 g of C₈H₁₈ is burned (reacted with O₂) to form two products: CO₂ and H₂O.
2) Write a balanced chemical equation for this reaction and construct a grid.
3) What mass of O₂ would be required and what mass of CO₂ and H₂O are produced?

By now most students are comfortable with the routine—only minor adjustments from previous analogies need to be clarified:

The bottom row is now labeled moles instead of count. Of course the number of moles actually does represent a number, not a mass or volume. It’s important to keep emphasizing this to students (20).
- The top row (amount) is something that can be measured in a lab: mass in grams.
- The middle row holds the conversion information necessary to relate moles to mass (molar mass).

If necessary, prompt students to follow the set-up steps:
A) Write a balanced chemical equation and construct Bill’s Box underneath.
B) Fill in boxes: with the problem-supplied starting value(s), identifying what is being asked (?) and then generate any needed conversion information (in this case: molar mass).
C) Calculate answers by navigating from one box to another. Move vertically (top↔bottom) in any column but move horizontally only along the bottom line.

After “step B” the grid is fully set-up. See figure 4.

<table>
<thead>
<tr>
<th>amount</th>
<th>conversion information (gfm)</th>
<th>moles</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.45 g</td>
<td>114.2 g/mol</td>
<td>mol</td>
</tr>
<tr>
<td>25 O₂</td>
<td>32.00 g/mol</td>
<td>mol</td>
</tr>
<tr>
<td>16 CO₂</td>
<td>44.01 g/mol</td>
<td>mol</td>
</tr>
<tr>
<td>18 H₂O</td>
<td>18.02 g/mol</td>
<td>mol</td>
</tr>
</tbody>
</table>

Figure 4. The grid after problem type 4 is fully set-up but before any calculations.
The full set-up and subsequent calculations for problem type 4 are represented in figure 5. Once again starting point for calculations is indicated by “∗”) and shaded green; italicized numbers represent intermediate answers and bold numbers shaded red represent final answers.

<table>
<thead>
<tr>
<th>amount</th>
<th>23.45 g</th>
<th>82.14 g</th>
<th>72.30 g</th>
<th>33.30 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information (gfm)</td>
<td>114.2 g/mol</td>
<td>32.00 g/mol</td>
<td>44.01 g/mol</td>
<td>18.02 g/mol</td>
</tr>
<tr>
<td>moles</td>
<td>0.2053 mol</td>
<td>2.567 mol</td>
<td>1.643 mol</td>
<td>1.848 mol</td>
</tr>
</tbody>
</table>

Figure 5. Completed grid after answering problem type 4.

If all calculations are done correctly, the sum of the starting masses (reactants) equals the sum of the final mass (two products): both are 105.6 grams. This is a reflection of The Law of Conservation of Mass and also a method of checking for errors. This realization is a dramatic “Oh, wow!” for most of most students and hooks them on the value of the Bill’s Box approach.

**Advance to a limiting reactant with moles and mass**

**Problem Type 5**

1) 56.78 g C₈H₁₈ is burned with 156.7 g O₂ to form CO₂ and H₂O
2) Which reactant is the limiting reactant? Which reactant is in excess?
3) What mass of CO₂ and H₂O are produced?
4) After the reaction is complete, what mass of the reactant in excess remains?

Once again Bill’s Box set-up is used (figure 6):

<table>
<thead>
<tr>
<th>amount</th>
<th>56.78 g</th>
<th>156.7 g</th>
<th>? g</th>
<th>? g</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>114.2 g/mol</td>
<td>32.00 g/mol</td>
<td>44.01 g/mol</td>
<td>18.02 g/mol</td>
</tr>
<tr>
<td>moles</td>
<td>mol</td>
<td>mol</td>
<td>mol</td>
<td>mol</td>
</tr>
</tbody>
</table>

Figure 6. The grid after problem type 5 is fully set-up but before any calculations.
This is similar to the tricycle limiting reactant problem—question 3. Suggest to students that they place an asterisk (*) in the mole box of the limiting reactant and call this box “calculation central” because all subsequent calculations originate from that point. See figure 7.

\[
2 \text{C}_8\text{H}_{18} + 25 \text{O}_2 \rightarrow 16 \text{CO}_2 + 18 \text{H}_2\text{O}
\]

<table>
<thead>
<tr>
<th>amount</th>
<th>56.78 g ★</th>
<th>156.7 g ★</th>
<th>? g</th>
<th>? g</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion info</td>
<td>114.2 g/mol</td>
<td>32.00 g/mol</td>
<td>44.01 g/mol</td>
<td>18.02 g/mol</td>
</tr>
<tr>
<td>moles</td>
<td>0.4972 mol</td>
<td>4.897 mol ★</td>
<td>3.134 mol</td>
<td>3.978 mol</td>
</tr>
</tbody>
</table>

Figure 7. Partially completed grid after identifying the limiting reactant for problem type 5.

The moles of the excess reactant consumed (C\textsubscript{8}H\textsubscript{18}) and the moles and mass remaining can be logically and conveniently be made and recorded below Bill’s Box. The entire scope of problem type 5 can be completed with the single, compact and logical grid set-up (figure 8).

\[
2 \text{C}_8\text{H}_{18} + 25 \text{O}_2 \rightarrow 16 \text{CO}_2 + 18 \text{H}_2\text{O}
\]

<table>
<thead>
<tr>
<th>amount</th>
<th>56.78 g ★</th>
<th>156.7 g ★</th>
<th>137.9 g</th>
<th>63.53 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion info</td>
<td>114.2 g/mol</td>
<td>32.00 g/mol</td>
<td>44.01 g/mol</td>
<td>18.02 g/mol</td>
</tr>
<tr>
<td>moles</td>
<td>0.4972 mol</td>
<td>4.897 mol ★</td>
<td>3.134 mol</td>
<td>3.526 mol</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
2/25 & \times (more) \\
2/25 & \times (less)
\end{align*}
\]

\[
\begin{align*}
x \times 114.2 \text{ g/mol} \\
0.1054 \text{ mol (excess)}
\end{align*}
\]

12.04 g excess C\textsubscript{8}H\textsubscript{18}

Figure 8. Completed grid after fully answering problem type 5.

Note that all amounts relevant to C\textsubscript{8}H\textsubscript{18} logically remain in the same column: coefficients, initial mass, molar mass (g/mol), initial moles, moles consumed, moles excess and finally mass excess. Once again the sum of the initial mass of the reactants equals what remains: the sum of the mass of excess reactant plus the mass of both products (213.5 g).
Add aqueous solution stoichiometry

Problem Type 6
1) Mossy Zn reacts with aqueous HCl.
2) If 0.567 L of aqueous HCl is used, what mass of Zn is needed and what mass of ZnCl₂ and H₂ are produced?

This question is presented as guided inquiry by withholding the molarity. The question is unanswerable and, like problem type 3, students are forced to search for a device to relate solution volume to the number of particles—concentration: mol/L \((16,26)\). Aqueous solutions are measured by volume and molarity is the conversion information required to make volume-to-mole calculations: \(\text{mol} = \text{L} \cdot \text{M}\) and \(\text{L} = \text{mol}/\text{M}\). Once the concentration is supplied \((6.20 \text{ M in this example})\) the Bill’s Box set-up will look like figure 9.

\[
\begin{align*}
\text{Zn (s)} & + 2 \text{HCl (aq)} \rightarrow \text{ZnCl}_2 & + & \text{H}_2 \\
\text{amount} & & ? \text{ g} & 0.567 \text{ L} & ? \text{ g} & ? \text{ g} \\
\text{conversion information (gfm & molarity)} & 65.4 \text{ g/mol} & 6.20 \text{ mol/L} & 136 \text{ g/mol} & 2.02 \text{ g/mol} \\
\text{moles} & \text{mol} & \text{mol} & \text{mol} & \text{mol}
\end{align*}
\]

Figure 9. The grid after problem type 6 is fully set-up but before any calculations.

\[
\begin{align*}
\text{Zn (s)} & + 2 \text{HCl (aq)} \rightarrow \text{ZnCl}_2 & + & \text{H}_2 \\
\text{amount} & 115 \text{ g} & 0.567 \text{ L} & 239 \text{ g} & 3.55 \text{ g} \\
\text{conversion information (gfm & molarity)} & 65.4 \text{ g/mol} & 6.20 \text{ mol/L} & 136 \text{ g/mol} & 2.02 \text{ g/mol} \\
\text{moles} & 1.76 \text{ mol} & 3.52 \text{ mol} & 1.76 \text{ mol} & 1.76 \text{ mol}
\end{align*}
\]

Figure 10. Completed grid after fully answering problem type 6.
Standardization of a base (NaOH) using a primary standard (KHP)

**Problem Type 7**
1) Prepare 500.0 mL of approximately 1 M NaOH.
2) Standardize this solution
3) Use KHP (KHC₈H₄O₄) as the primary standard & phenolphthalein indicator.
4) Precisely mass 2-3 grams of KHP and titrate with the NaOH solution.
5) Being faithful to significant figures, calculate the molarity of the NaOH (aq).

To answer this question, students must have the understanding that in titrations, a color change occurs at the equivalence point where the moles of the acid and base are present in the stoichiometric amounts reflected by the coefficients.

Once the mass of KHP is measured (2.35g for this example) and titrated with the NaOH solution (12.16mL for this example), the concentration can be calculated. Note that, given the question asked, not all boxes need to be filled in.

<table>
<thead>
<tr>
<th>KHC₈H₄O₄ (s) + NaOH (aq) → KNaC₈H₄O₄ (aq) + H₂O (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>amount</td>
</tr>
<tr>
<td>conversion information</td>
</tr>
<tr>
<td>moles</td>
</tr>
</tbody>
</table>

Figure 11. The grid after problem type 7 is fully set-up but before any calculations.

<table>
<thead>
<tr>
<th>KHC₈H₄O₄ (s) + NaOH (aq) → KNaC₈H₄O₄ (aq) + H₂O (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>amount</td>
</tr>
<tr>
<td>conversion information</td>
</tr>
<tr>
<td>moles</td>
</tr>
</tbody>
</table>

Figure 12. Completed grid after fully answering problem type 7.
Determine the equivalent weight of an unknown acid

**Problem Type 8**

1) The titration of a 336mg sample of a diprotic acid requires 42.2mL of 0.104M NaOH.
2) What is the equivalent weight of this acid?

Because a diprotic acid is being titrated with a monobasic base, the base-to-acid mole ratio is 2:1. Again note that, given the question asked, not all boxes need to be filled in.

\[
\text{H}_2\text{X} \ (s) \ + \ 2 \ \text{NaOH} \ (aq) \rightarrow \ \text{Na}_2\text{X} \ (aq) \ + \ 2 \ \text{H}_2\text{O} \ (l)
\]

<table>
<thead>
<tr>
<th>amount</th>
<th>0.336 g</th>
<th>(0.0422 \text{ L} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>? g/mol</td>
<td>0.104 mol/L</td>
</tr>
<tr>
<td>moles</td>
<td>(mol)</td>
<td>(mol)</td>
</tr>
</tbody>
</table>

Figure 13. The grid after problem type 8 is fully set-up but before any calculations.

The number of moles of the unknown acid is calculated from the moles of NaOH. The molar mass of this unknown acid is then calculated: g/m = grams acid/moles acid. Given a list of diprotic acids, students should be able to make an identification based on their results. For this example, tartaric acid would be reasonable.

\[
\text{H}_2\text{X} \ (s) \ + \ 2 \ \text{NaOH} \ (aq) \rightarrow \ \text{Na}_2\text{X} \ (aq) \ + \ 2 \ \text{H}_2\text{O} \ (l)
\]

<table>
<thead>
<tr>
<th>amount</th>
<th>0.336 g</th>
<th>(0.0422 \text{ L} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>153 g/mol</td>
<td>0.104 mol/L</td>
</tr>
<tr>
<td>moles</td>
<td>(0.00219 \text{ mol})</td>
<td>(0.00439 \text{ mol})</td>
</tr>
</tbody>
</table>

Figure 14. Completed grid after fully answering problem type 8.
Acid-base stoichiometry with a diprotic acid & a standard monobasic base.

**Problem Type 9**

1) Using phenolphthalein as an indicator, 0.01500 L of H$_2$SO$_4$ is titrated with 0.03456 L of 0.1628 M NaOH.
2) What is the concentration of the H$_2$SO$_4$?

The same basic set-up is used (figure 15). Note that again, given the question asked, not all boxes need to be filled in.

\[
\text{H}_2\text{SO}_4 \text{(aq)} + 2 \text{NaOH (aq)} \rightarrow \text{Na}_2\text{SO}_4 \ + \ 2 \text{H}_2\text{O}
\]

<table>
<thead>
<tr>
<th>amount</th>
<th>0.01500 L</th>
<th>0.03456 L</th>
<th>*</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion info</td>
<td>? mol/L</td>
<td>0.1628 mol/L</td>
<td></td>
</tr>
<tr>
<td>moles</td>
<td>? mol</td>
<td>? mol</td>
<td></td>
</tr>
</tbody>
</table>

Figure 15. The grid after problem type 9 is fully set-up but before any calculations.

In this case, the number of moles of H$_2$SO$_4$ is calculated from the moles of NaOH. The molarity of H$_2$SO$_4$ is then calculated: M = mol/L (figure 16).

\[
\text{H}_2\text{SO}_4 \text{(aq)} + 2 \text{NaOH (aq)} \rightarrow \text{Na}_2\text{SO}_4 \ + \ 2 \text{H}_2\text{O}
\]

<table>
<thead>
<tr>
<th>amount</th>
<th>0.01500 L</th>
<th>0.03456 L</th>
<th>*</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion info</td>
<td>0.1875 mol/L</td>
<td>0.1628 mol/L</td>
<td></td>
</tr>
<tr>
<td>moles</td>
<td>0.002813 mol</td>
<td>0.005626 mol</td>
<td></td>
</tr>
</tbody>
</table>

Figure 16. Completed grid after fully answering problem type 9.
Add ideal gas stoichiometry

Problem Type 10

1) How many grams of potassium chlorate are needed to generate 2.00 L of oxygen?
2) Assume ideal gas behavior; the ideal gas constant equals 0.08206 L•atm/mol•K
3) The room conditions are: T = 21˚C and P = 1.00 atm.

Assume ideal gas behavior, convert °C to Kelvin and select the appropriate gas constant.
Solving for moles (bottom line) gives: $n = \frac{PV}{RT}$
Solving for volume (top line) gives: $V = \frac{nRT}{P}$

$$2 \text{ KClO}_3 (s) \rightarrow 2 \text{ KCl} (s) + 3 \text{ O}_2 (g)$$

<table>
<thead>
<tr>
<th>amount</th>
<th>? g</th>
<th>2.00 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information (gfm, P &amp; T)</td>
<td>122.6 g/mol</td>
<td>21˚C = 294 K 1.00 atm</td>
</tr>
<tr>
<td>moles</td>
<td>mol</td>
<td>mol</td>
</tr>
</tbody>
</table>

Figure 17. The grid after problem type 10 is fully set-up but before any calculations.

<table>
<thead>
<tr>
<th>amount</th>
<th>6.78 g</th>
<th>2.00 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>122.6 g/mol</td>
<td>21˚C = 294 K 1.00 atm</td>
</tr>
<tr>
<td>moles</td>
<td>0.0553 mol</td>
<td>0.0829 mol</td>
</tr>
</tbody>
</table>

Figure 18. Completed grid after fully answering problem type 10.
Combining everything: limiting reactant with solids, solutions and gases.

**Problem Type 11**

1) Four copper pennies (12.3 g) react with 0.0405 L 16.0 M HNO$_3$.
2) Which reactant is in excess and by how much?
3) At 25 °C and 0.987 atm what volume of NO$_2$ gas is produced?

All forms of conversion information are required: molar mass, molarity and temperature and pressure conditions to use in the ideal gas equation (figure 19).

<table>
<thead>
<tr>
<th>amount</th>
<th>12.3 g</th>
<th>0.0405 L</th>
<th>? L</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>63.6 g/mol</td>
<td>16.0 mol/L</td>
<td>25°C = 298K 0.987 atm</td>
</tr>
<tr>
<td>moles</td>
<td>mol</td>
<td>mol</td>
<td>mol</td>
</tr>
</tbody>
</table>

Figure 19. The grid after problem type 11 is fully set-up but before any calculations.

After the limiting reactant is identified (★) and all calculations are complete, the grid will look like figure 20.

<table>
<thead>
<tr>
<th>amount</th>
<th>12.3 g</th>
<th>0.0405 L</th>
<th>8.03 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>conversion information</td>
<td>63.6 g/mol</td>
<td>16.0 mol/L</td>
<td>25.0 °C = 298 K 0.987 atm</td>
</tr>
<tr>
<td>moles</td>
<td>0.193 mol</td>
<td>0.648 mol ★</td>
<td>0.386 mol 0.324 mol</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
x \cdot 1/4 \\
-0.162 \text{ mol} \text{ (consumed) } \\
0.031 \text{ mol} \text{ (excess)} \\
\text{x 63.6 g/mol} \\
= 2.0 \text{ g} \text{ EXCESS Cu}
\end{align*}
\]

Figure 20. Completed grid after fully answering problem type 11.
Teaching tips to consider:

- Encourage students to set up Bill’s Box, enter all problem-supplied values, identify all questions and record all conversion information before doing any calculations. This helps them frame the problem, saves time and facilitates rapid and accurate calculations. Students instinctively stop using question marks and learn to circle or simply mentally identify “target boxes” so they can record answers without having to erase.
- A similar 3-row grid is used to organize equilibrium problems. These are called ICE boxes from the row labels: initial, change and equilibrium \( (31,32,33) \).
- Encourage students to write appropriate units in all boxes during the set-up; this helps them enter the necessary conversion information and use the appropriate formulas.
- Encourage students to maintain the maximum allowable significant figures during their calculations and round only at the end.
- Explain that horizontal calculations should be made only along the bottom line because usually amounts of reactants and products are not directly related to one another.
- Amounts of reactants and products can be directly related to one another only with gas volumes under identical conditions of temperature and pressure (Avogadro’s Law).
- Emphasize that formulas (including subscripts) and NOT coefficients are relevant in determining molar mass.
- To help students correctly inter-convert mass and moles, encourage them to ask, “Is the mass more or less than one mole? Is my answer reasonable?” This helps them decide whether they should divide or multiple by the molar mass.
- To make volume-to-mole conversions for gases the ideal gas equation is used. Remind students that temperatures need to be in Kelvin and the ideal gas constant used must match the pressure units used.

Summary

Using the Bill’s Box set-up one can start from any point on Bill’s Box and move logically to any other point. The author has found it to be an effective teaching tool because it starts students a strong conceptual understanding and provides them with a simple and logical framework. From this beginning students comfortably expand their stoichiometry skills. Former chemistry students regularly email the author from college and report that the Bill’s Box method prepared them exceptionally well for their college-level stoichiometry. Some examples:

“I still put Bill’s box to good use…”
“I've taught Bill's Box to five or six of my classmates and they absolutely love it.”
“...Bill’s box is the greatest invention ever.”
“I am still using Bill's Box.”
“I have found Bill's box to be very very helpful! I actually taught my discussion TA how to do Bill's box and he has used it to teach my discussion group how to do certain calculations.”
“I have been teaching the students in my lecture that I sit near how to do Bill's box and they absolutely love it!”

William Struck
struckwi@msu.edu
Literature Cited