Lesson: Stoichiometry Set-Up Method

FOR THE TEACHER

Summary
In this lesson, students will learn how to follow a process of visual cues in combination with a step-by-step problem solving method for different types of stoichiometric problems. This method can be particularly beneficial for students who struggle with completing multi-step calculations.

Grade Level
High School

Objectives
By the end of this lesson, students should be able to
- Apply a specific problem solving method to successfully answer any stoichiometry problem.
- Use dimensional analysis to complete a calculation.

Chemistry Topics
This lesson supports students’ understanding of
- Stoichiometry
- Dimensional Analysis
- Molarity
- Gas Laws

Time
Teacher Preparation: None
Lesson: 60 minutes per topic

Materials
- Stoichiometry guides for the particular topic of focus.
- Calculator
- Periodic table

Safety
- No safety considerations are needed for this activity.

Teacher Notes
- The stoichiometry set-up method is very valuable for students who struggle to complete multi-step calculations, and dimensional analysis.
- Use these as student-handouts, or guides when introducing the method of calculating stoichiometry problems would be most beneficial.
FOR THE STUDENT

Stoichiometry Problems

Steps for the stoichiometry set-up method

1. Write a balanced chemical equation.

2. Write what is given and what needs to be calculated (X) on the equation.
   a) Data in moles go under the equation.
   b) Data in other units go above the equation.

3. Draw a path, using arrows, from the given amount to what needs to be calculated on your chemical equation.
   a) Separate vertical and horizontal arrows.
   b) Horizontal arrows must go under the equation.

4. Perform the appropriate calculations along the path.

Putting the steps into practice
To show how this method is used to convert the given unit to the unit asked for in the problem, I will solve a typical stoichiometric problem using this mechanism. Here is a two-part sample problem:

If a 2.8 g sample of mercuric oxide is decomposed by heating:
   a) How many grams of mercury will be produced?
   b) How many moles of oxygen will be produced?

Steps for solving sample question part a
1. Write the balanced chemical equation.

   \[ 2 \text{HgO} \rightarrow 2 \text{Hg} + \text{O}_2 \]

2. Write what is given and what needs to be calculated on the equation (moles go under the equation all other units go above the equation).

   \[ \frac{2.8 \text{ g}}{2 \text{ HgO}} = \frac{X \text{ g}}{2 \text{ Hg} + \text{O}_2} \]

3. Draw a path from what is given to what needs to be calculated on your chemical equation (separating vertical and horizontal arrows and having horizontal arrows go under the equation).

   \[ \frac{2.8 \text{ g}}{2 \text{HgO} \rightarrow 2 \text{Hg} + \text{O}_2} \]
4. Perform the calculations along the path. Here is where the arrows provide a map for the student to follow. Just like the animal mole lives underground, the unit of mole lives under the equation. So the first arrow directs the student to convert what they are given (the 2.8 g of mercuric oxide) to moles of mercuric oxide (under the HgO, which is where the moles live).

**Corresponding calculation for the first arrow:**

\[
2.8 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} = \]

The second arrow goes from under HgO to under Hg. Therefore, it asks the student to convert moles of HgO to moles of Hg.

**Corresponding calculation for the second arrow:**

\[
2.8 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} \times \frac{2 \text{ mol Hg}}{2 \text{ mol HgO}} = \]

The last arrow goes from under Hg (from moles of Hg) to above Hg (to grams of Hg).

**Corresponding calculation for the third arrow:**

\[
2.8 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} \times \frac{2 \text{ mol Hg}}{2 \text{ mol HgO}} \times \frac{200.6 \text{ g Hg}}{1 \text{ mol Hg}} = 2.6 \text{ g of Hg} \]

**Steps for solving sample question part b**

1. Balanced chemical equation.

   \[
   2 \text{ HgO} \rightarrow 2 \text{ Hg} + \text{ O}_2 \]

2. The student would place \(X\) under the oxygen (because the student is asked to solve for moles of oxygen).

   \[
   2.8 \text{ g HgO} \rightarrow 2 \text{ Hg} + \text{ O}_2 \quad X \text{ mol} \]

3. Draw a path from the given data to what needs to be calculated.

   \[
   2.8 \text{ g HgO} \rightarrow 2 \text{ Hg} + \text{ O}_2 \quad X \text{ mol} \]

4. Perform the calculations along the path. The first arrow shows the student to go from above the HgO (grams of HgO) to under the HgO (moles of HgO).
**Corresponding calculation for the first arrow:**

\[
2.8 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} = 0.0128 \text{ mol HgO}
\]

The second arrow shows the student to go from under the HgO (moles of HgO) to under the O\(_2\) (moles of O\(_2\)).

**Corresponding calculation for the second arrow:**

\[
2.8 \text{ g HgO} \times \frac{1 \text{ mol HgO}}{216.6 \text{ g HgO}} \times \frac{1 \text{ mol O}_2}{2 \text{ mol HgO}} = 0.0065 \text{ mol O}_2
\]

Notice that the number of arrows corresponds to the number of conversion factors in the dimensional analysis.

**Gas Laws**

This method can also be used to solve stoichiometric problems involving gases, when the conditions are not at STP. If the vertical arrow passing through a gas points down (pointing to moles), the student uses the ideal gas law to solve for moles represented as \( n \) in the ideal gas law \( (n=PV/RT) \), where \( n \) is the number of moles of the gas, \( P \) is the gas' pressure, \( V \) is the volume of gas, \( R \) is the ideal gas law constant, and \( T \) is the Kelvin temperature of the gas. If the vertical arrow passing through a gas points up (pointing to L), the student uses the ideal gas law to solve for \( V \) \( (V=nRT/P) \). The following sample problem illustrates this:

What volume of carbon dioxide will be collected at 25°C and .965atm when 25.6g of calcium carbonate undergoes decomposition?

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**Step 1:** write the balanced chemical equation:

\[
\text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g)
\]

**Step 2:** write what is known and what is to be calculated on the equation (moles go under the equation all other units go above the equation).

\[
25.6 \text{ g} \quad X \text{ L} \\
\text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g)
\]

**Step 3:** draw the path from the given data to what needs to be calculated.

\[
25.6 \text{ g} \\
\text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g)
\]

**Step 4:** complete the calculations along the path.
A common mistake that students make is to use the ideal gas law with materials that are not gases. If the arrow passes through a gas, they should use the ideal gas law. If the arrow does not pass through a gas, the ideal gas law should not be used. In this example, because the first arrow passes through solid CaCO$_3$ (not a gas), the student does not use the ideal gas law equation for the first step.

**Corresponding calculation for the first arrow:**

\[ 25.6 \text{ g CaCO}_3 \times \frac{1 \text{ mol CaCO}_3}{100.1 \text{ g CaCO}_3} = \]

The second arrow goes from under CaCO$_3$ (moles of CaCO$_3$) to under CO$_2$ (moles of CO$_2$).

**Corresponding calculation for the second arrow:**

\[ 25.6 \text{ g CaCO}_3 \times \frac{1 \text{ mol CaCO}_3}{100.1 \text{ g CaCO}_3} \times \frac{1 \text{ mol CO}_2}{1 \text{ mol CaCO}_3} = \]

The third arrow passes only through the gas CO$_2$ so it is the only place where a gas law should be used. Because the arrow points to the $X$ L the ideal gas law should be solved for the variable measured in liters which is $V$ ($V = nRT/P$). However, to do this calculation, the moles of CO$_2$ ($n$) first needs to be calculated using the stoichiometry from step 1 and step 2.

\[ 25.6 \text{ g CaCO}_3 \times \frac{1 \text{ mol CaCO}_3}{100.1 \text{ g CaCO}_3} \times \frac{1 \text{ mol CO}_2}{1 \text{ mol CaCO}_3} = 0.255744255 \text{ mol CO}_2 \]

Now that the number of moles of CO$_2$ is known the ideal gas law can be used. It should also be noted that since we are in the middle of series of multiplication steps, the number of significant figures recorded in the answer for $n$ should not yet be rounded.

**Corresponding calculation for the third arrow:**

\[ V = \frac{nRT}{P} = \frac{(0.255744255 \text{ mol})(0.08206 \text{ L atm/mol K})(298 \text{ K})}{0.965 \text{ atm}} = 6.48 \text{ L CO}_2 \]

Notice that I have used parentheses instead of multiplication signs in the solution of the ideal gas law. Counting the number of multiplication signs used in the student’s attempted solution will not match with the number of arrows on their drawn path if times signs are used in the gas law. A general rule that may be helpful is to use a different symbol to represent multiplication signs in the gas law (parentheses or asterisks) than is used in the stoichiometry.
Molarity Problems

Another type of problem that benefits from this process is using a downward arrow through the data for a given gas and using stoichiometry to solve for the molarity of a solution.

If .033 L of hydrogen is collected at 0 °C and 1.00 atm from the reaction of solid aluminum and .500-M hydrochloric acid, what volume of .500-M HCl reacted?

**Step 1**: Write the balanced chemical equation.

\[ 2 \text{ Al (s)} + 6 \text{ HCl (aq)} \rightarrow 2 \text{ AlCl}_3 (aq) + 3 \text{ H}_2 (g) \]

**Step 2**: Write what is given and what needs to be calculated (moles go under the equation all other units go above the equation).

\[ \text{X L} \quad .033 \text{ L} \]

\[ 2 \text{ Al (s)} + 6 \text{ HCl (aq)} \rightarrow 2 \text{ AlCl}_3 (aq) + 3 \text{ H}_2 (g) \]

**Step 3**: Draw the path from the given data to what needs to be calculated.

**Step 4**: Perform the calculations.

The first arrow goes only through the gas H\(_2\) and points to moles of (underneath) H\(_2\), so the ideal gas law has to be solved for “moles of H\(_2\)” (n = PV/RT). Since this is a gas law, I will use the * to represent the multiplication in the gas law and the typical “x” as the stoichiometric multiplication.

\[
\text{n} = \frac{\text{PV}}{\text{RT}} = \frac{1.00 \text{ atm} \times .033 \text{ L}}{.08206 \text{ L atm/mol K} \times 273 \text{ K}} = .001473057773 \text{ mol H}_2
\]

The second arrow goes from under H\(_2\) (mol H\(_2\)) to under HCl (mol HCl).

\[
.001473057773 \text{ mol H}_2 \times 6 \text{ mol HCl} = \text{ } \frac{3 \text{ mol H}_2}{3 \text{ mol HCl}}
\]

The third arrow goes through an aqueous solution of HCl. When a vertical arrow goes through an aqueous solution, its molarity needs to be used. Since the solution is .500-M HCl, 1 L of this solution contains .500 moles of HCl. (.500 mol HCl = 1-L HCl solution)
This problem also illustrates a way to use the molar volume of any gas at STP as 22.4 L/mol. Since H₂ is .033 L of a gas at STP, the student could also change liters of H₂ to moles of H₂ in the following manner and then finish the problem as previously shown:

\[
\frac{0.033 \text{ L} \text{ H}_2 \times 1 \text{ mol H}_2 \times 6 \text{ mol HCl} \times 1 \text{ L HCl}}{22.4 \text{ L H}_2 \times 3 \text{ mol H}_2 \times 0.500 \text{ mol HCl}} = 0.0059 \text{ L or 5.9 mL HCl}
\]

**Electrolysis applications**

A final way to use this technique is with an electrolysis problem. The following problem will show the way to use time to measure the flow of electrons and then the standard stoichiometry method to answer an electrolysis problem.

If a 10.0-amp current flows into a solution of AlCl₃ for 2.00 minutes, what mass of Al will be plated on the cathode?

**Step 1:** The balanced chemical equation.

\[
\text{Al}^{3+}(aq) + 3 \text{ e}^- \rightarrow \text{Al}(s)
\]

**Step 2:** Write what is given and what needs to be calculated.

\[
\begin{array}{c}
2.00 \text{ min} \\
\text{Al}^{3+}(aq) + 3 \text{ e}^- \rightarrow \text{Al}(s)
\end{array}
\]

**Step 3:** Draw the path from what is given to what needs to be calculated.

\[
\begin{array}{c}
\text{Al}^{3+}(aq) + 3 \text{ e}^- \rightarrow \text{Al}(s) \\
\text{2.00 min} \quad X \text{ g}
\end{array}
\]

**Step 4:** Perform the calculations. The flow of electrons being measured in amps needs to be explained along with the Faraday constant: 10.0 amps means that 10.0 coulombs of charge flow into the Al³⁺ solution each second and 1 mole of electrons contain a charge of 96,485 coulombs (the Faraday constant). Once through the first arrow, it is the same stoichiometry as previously directed.

\[
2.00 \text{ min} \times \frac{60 \text{ sec}}{1 \text{ min}} \times \frac{10.0 \text{ coul}}{1 \text{ sec}} \times \frac{1 \text{ mol e}^-}{96,485 \text{ coul}} \times \frac{1 \text{ mol Al}}{3 \text{ mol e}^-} \times \frac{27.0 \text{ g Al}}{1 \text{ mol Al}} = 0.336 \text{ g Al}
\]
Summary of the set up

After the students have learned all of the various molar conversions, I condense them into a final table that shows the possible units above and below the chemical equations used in stoichiometric problems and the conversion factor that will get them from above the equation to below and vice versa:

<table>
<thead>
<tr>
<th>grams</th>
<th>particles</th>
<th>L gas at STP</th>
<th>L gas not at STP</th>
<th>L of a solution</th>
<th>time</th>
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Coefficients from chemical equation

Using this table as a guide, the student can place a given number and its unit in the stoichiometric problem and X with its unit above or below the final chemical formula. The type of molar conversion that needs to be used to convert the given unit to moles is given on the downward arrow, while the mole-to-mole ratio is found from the chemical equation’s coefficients and is written on the horizontal arrow on the bottom of the table. The needed conversion factor for moles to the final unit asked for in the problem is indicated by the upward arrow in the table.