Solving Word Problems based on Equations of Chemical Reactions. (Draft)

Word problems about chemical reactions have to be solved in two major steps. First, you have to write and balance the equation of the reaction described in words. Second, you have to identify known quantities and calculate the sought quantities using the help of the equation. Remember, the equation is the key. If you cannot write and balance the equation, there is no point in proceeding any further. Below there are several examples of how to solve word problems.

1. How many moles of hydrochloric acid are needed to dissolve 39.0 grams of aluminum hydroxide?

   The first step is to write the equation of the reaction. It involves two reagents: aluminum hydroxide, and hydrochloric acid. It is crucial to recall that the formula of aluminum hydroxide is Al(OH)₃. (Explain why Al(OH)₃, not AlOH.) The formula of hydrochloric acid is HCl. As in any reaction between acid and base water and salt will form:

   \[ \text{Al(OH)}_3 + 3 \text{HCl} \rightarrow \text{AlCl}_3 + 3 \text{H}_2\text{O} \]

   Once the equation is written, the solution is straightforward. It is convenient to organize the solution in form of a table:

<table>
<thead>
<tr>
<th></th>
<th>Al(OH)₃</th>
<th>+ 3 HCl→</th>
<th>AlCl₃</th>
<th>+ 3 H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>moles</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>grams</td>
<td>39.0g</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   This way the given and the sought become obvious. Note, it does not matter which line is moles and which is grams. I prefer to keep moles closer to the equation, since the equation relates moles, not grams.

   Therefore, the amount of aluminum hydroxide has to be expressed in moles rather than in grams. This can be easily done by dividing the total mass of the substance by the mass of one mole of it. Just like a big sack of sugar would be packaged into small packages. Here the total mass of the substance plays role of the sack of sugar that needs to be packaged into 1 molar packages.

<table>
<thead>
<tr>
<th>substances</th>
<th>Al(OH)₃</th>
<th>+ 3 HCl→</th>
<th>AlCl₃</th>
<th>+ 3 H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>moles</td>
<td>0.500 mole</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \leq 78.0 \text{ g/mole} )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grams</td>
<td>39.0g</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   Once the number of moles of aluminum hydroxide is known, the number of moles of hydrochloric acid can be immediately calculated using the proportions in the equation. Indeed, if one mole of aluminum hydroxide requires 3 moles of hydrochloric acid, then half mole requires only half of this amount, \textit{i.e.} only \( 3/2 \) mole of hydrochloric acid.
substances | Al(OH)₃ | + 3 HCl→ | AlCl₃ | + 3 H₂O
--- | --- | --- | --- | ---
moles | 1 mole | ➔ 3 mole | | ?
| 0.500 mole | ➔ 1.50 mole | | ?
grains | 39.0g

The answer is 1.50 moles of HCl. This number shows how many moles of HCl are needed to dissolve not one mole of aluminum hydroxide, but the actual given amount, i.e. 39.0 g or only 0.500 mole.

2. How many grams of precipitate will form in reaction between 10 g of calcium bromide and an excess of silver nitrate?

As always, the right approach to this problem is through the equation of the chemical reaction:

\[ \text{CaBr}_2 + 2 \text{AgNO}_3 \rightarrow \text{Ca(NO}_3)_2 + 2 \text{AgBr}\downarrow \]

where the down arrow ↓ indicates that silver bromide is the precipitate. This the problem can be rephrased in the following way:

How many grams of precipitate silver bromide will form in reaction between 10 g of calcium bromide and an excess of silver nitrate?

Again, once the equation is written and balanced, the rest of the solution can be organized into a table. The table shows what is given, what to find and how to find it (arrows indicate the steps):

| | CaBr₂ | + 2 AgNO₃ | → Ca(NO₃)₂ | + 2 AgBr↓
--- | --- | --- | --- | ---
moles | | | | |
grains | 10 g

Applying these 3 steps to the problem we shall add new content into our table:

| | CaBr₂ | + 2 AgNO₃ | → Ca(NO₃)₂ | + 2 AgBr↓
--- | --- | --- | --- | ---
moles | 1 mole | | | 2 moles
| 0.050 mole | | | 0.10 mole
| grams | ➔ 200 g/mole | | | ➔ 1.187 g/mole
10 g

3. How many grams of gas will evolve in reaction between 20.0 g of chalk and an excess of sulfuric acid?

Exactly like before, one must start solving of this problem with writing the equation of the chemical process described in words; remember that chalk is calcium carbonate:
CaCO\(_3\) + H\(_2\)SO\(_4\) \rightarrow\) CaSO\(_4\) + H\(_2\)CO\(_3\)

As the unstable carbonic acid breaks in the presence of the excess of sulfuric acid gas evolves:
H\(_2\)CO\(_3\) \rightarrow\) CO\(_2\)↑ + H\(_2\)O,

where the up arrow indicates evolution of gas. Combining the two equations gives us the total equation of the reaction:

\[
\text{CaCO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{CaSO}_4 + \text{CO}_2\uparrow + \text{H}_2\text{O}
\]

Once the equation is written, the problem can be reworded as following:

“How many grams of \textbf{gas carbon dioxide} will evolve in reaction between 20.0 g of \textit{chalk} \textbf{calcium carbonate} and excess of sulfuric acid?”

and the calculations can be organized into a table:

<table>
<thead>
<tr>
<th>moles</th>
<th>CaCO(_3)</th>
<th>+ H(_2)SO(_4)</th>
<th>\rightarrow CaSO(_4)</th>
<th>+ CO(_2)↑</th>
<th>+ H(_2)O</th>
</tr>
</thead>
<tbody>
<tr>
<td>grams</td>
<td>1 mole</td>
<td>0.200 mole</td>
<td>1 mole</td>
<td>0.200 mole</td>
<td>8.80 g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>moles</th>
<th>(\text{C}<em>8\text{H}</em>{18})</th>
<th>+ (\frac{25}{2}) O(_2)</th>
<th>\rightarrow 8 CO(_2)</th>
<th>+ 9 H(_2)O</th>
</tr>
</thead>
<tbody>
<tr>
<td>grams</td>
<td>2006 g</td>
<td></td>
<td></td>
<td>1193 g</td>
</tr>
<tr>
<td>volume</td>
<td>2.00 l = 2000 ml</td>
<td></td>
<td></td>
<td>1.19 l</td>
</tr>
</tbody>
</table>

4. How many liters of water will form upon combustion of 2.00 liters of octane (C\(_8\)H\(_{18}\))? Octane density is \(D_{\text{C}_8\text{H}_{18}} = 0.703 \text{ g/ml}\).

Even though the problem contains an additional information about the density of one of the reagents, start the solution exactly like in the previous cases, i.e. with writing the equation of the reaction:

\[
\text{C}_8\text{H}_{18} + \frac{25}{2}\text{O}_2 \rightarrow 8 \text{CO}_2 + 9 \text{H}_2\text{O}
\]

Never mind the fractional coefficient in front of the oxygen. As long as the equation is balanced, it is perfectly suitable for calculations. Let us organize the further solution in the form of a table similarly to the previous problems. Our table will need an additional line to accommodate volume - a new type of data provided in the problem. The arrows indicate the algorithm to solve the problem:

<table>
<thead>
<tr>
<th>moles</th>
<th>C(<em>8)H(</em>{18})</th>
<th>+ 25/2 O(_2)</th>
<th>\rightarrow 8 CO(_2)</th>
<th>+ 9 H(_2)O</th>
</tr>
</thead>
<tbody>
<tr>
<td>grams</td>
<td>1406 g</td>
<td></td>
<td></td>
<td>1193 g</td>
</tr>
<tr>
<td>volume</td>
<td>2.00 l = 2000 ml</td>
<td></td>
<td></td>
<td>1193 ml = 1.19 l</td>
</tr>
</tbody>
</table>

Let us perform the actions indicated by the algorithm above: