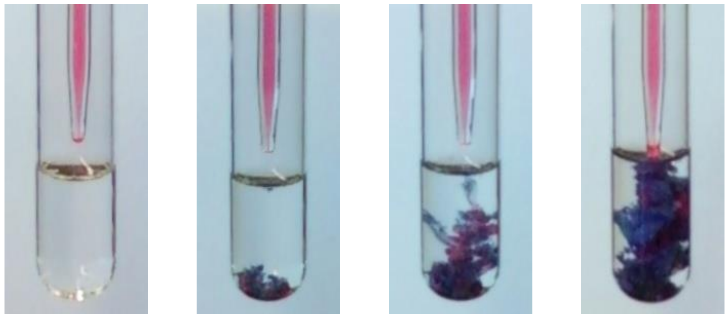
Precipitation Reactions and Percent Yield – Background



The ability to recognize, and predict the products for a precipitation reaction are critical skills for all General Chemistry students to master. Precipitation reactions are a class of chemical reaction in which a solid product is formed by combining at least two fully soluble, aqueous solutions. They are also known as double displacement, exchange, or metathesis reactions. These secondary names are a nod to the "chemical square dance" which occurs during the course of the reaction, and that must be understood to predict the products of the reaction.

Ionic compounds are composed of cations (+) and anions (-), in proportion to each other so that the total charge of the cations equals the total charge of the anions. When fully dissolved in water, the ions separate, with the appropriate stoichiometric coefficient for each ion.

$$Na_2SO_4(aq) \rightarrow 2Na^+(aq) + SO_4^{2-}(aq) \qquad (1)$$

or

$$Ba(NO_3)_2(aq) \rightarrow Ba^{2+}(aq) + 2NO_3^-(aq) \qquad (2)$$

The stoichiometry of each dissociated ion comes from the formula of the ionic compound. The charge of the dissociated ion can be determined from the periodic table trends for the monatomic ions (Na^+ and Ba^{2+} in equations 1 and 2), or *memorization* for the polyatomic ions. It is worth noting that you must recognize the presence of a polyatomic ion and understand that polyatomic ions DO NOT dissociate further into their constituent elements/ions.

When two aqueous, ionic solutions such as $Na_2SO_4(aq)$ and $Ba(NO_3)_2(aq)$ are combined, the dissociated cations and anions switch partners. The Na^+ ion, once paired with the negatively charged sulfate, ditches the sulfate ion and pairs up with the negatively charged nitrate ion. Likewise, the SO_4^{2-} ion, which just lost his/her partner, now pairs up with the positively charged barium ion. Remember, cations *always* pair up with anions and vice versa.

$$Na_2SO_4(aq) + Ba(NO_3)_2(aq) \longrightarrow \boxed{Na^+(aq) + NO_3^-(aq)} + \boxed{Ba^{2+}(aq) + SO_4^{2-}(aq)} \qquad (3)$$

Once you have the ions paired with their new partners, you must write the correct chemical formula for each new ionic compound. At this point, do not concern yourself with the existing stoichiometry of any particular ion; just write the correct chemical formula that balances the charges of the cation and anion. Also, remember that the cation is always written first and the anion follows. In our example, sodium is a (1+) ion and nitrate is a (1-) ion, therefore the correct formula for sodium nitrate is $NaNO_3$; we need only one of each ion to balance the charges. Meanwhile, barium is a (2+) ion and sulfate is a (2-) ion. Once again, we need only one of each ion to balance the charges and the correct formula for barium sulfate is $BaSO_4$.

$$Na_2SO_4(aq) + Ba(NO_3)_2(aq) \rightarrow NaNO_3 + BaSO_4 \text{ (unbalanced)} \qquad (4)$$

Lastly, the equation must be balanced, and states of matter must be assigned to the newly predicted products. Trends of solubility predict that $NaNO_3$ is soluble and we will assign (aq) as the state of matter. Barium sulfate is insoluble and will receive (s) as the state of matter. Balancing the equation and including the states of matter gives the final equation.

$$Na_2SO_4(aq) + Ba(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + BaSO_4(s) \qquad (5)$$

Every General Chemistry student is expected to be able to write a complete precipitation reaction when given a set of reagents. In today's experiment, you will mix aqueous solutions of cobalt(II) nitrate and sodium phosphate.

$$Co(NO_3)_2(aq) + Na_3PO_4(aq) \rightarrow \text{products} \qquad (6)$$

As part of your pre-lab preparation, you should complete equation 6 by predicting the products with states of matter, and balance the equation. While cobalt can take on various charges, as most transition metals do, equation 6 is not a redox reaction and the charge of the cobalt ion is consistent from reactant to product.

In today's experiment, you'll learn new techniques such as vacuum filtration and the proper use of a graduated pipet. You'll also be asked to calculate the percent yield for each of your precipitation reaction trials. Based upon the molar amounts of $Co(NO_3)_2$ and Na_3PO_4 used, you'll need to determine the limiting reagent, calculate the theoretical yield of the isolated precipitate, and finally calculate the percent yield for the formation of the precipitate.

$$\%\text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100 \qquad (7)$$

Calculations:

Prior to doing any calculations, you must write the complete balanced chemical equation for the precipitation reaction performed. In fact, this should be done as part of your pre-lab preparation. For each precipitation reaction trial, perform the following steps.

A. Calculate the mass of dried precipitate.

B. Calculate the moles of Na_3PO_4 used:

$$\text{moles } Na_3PO_4 = (\text{molarity of } Na_3PO_4\text{, mole/L}) \times \left(\frac{\text{volume of } Na_3PO_4\text{, mL}}{1000}\right)$$

C. Calculate the moles of $Co(NO_3)_2$ used:

$$\text{moles } Co(NO_3)_2 = (\text{molarity of } Co(NO_3)_2\text{, mole/L}) \times \left(\frac{\text{volume of } Co(NO_3)_2\text{, mL}}{1000}\right)$$

D. Using the balanced chemical equation, convert the moles of Na_3PO_4 to moles of precipitate:

$$\text{moles Na}_3\text{PO}_4 \times \left(\frac{\text{stoich. coeff. precipitate}}{\text{stoich. coeff. Na}_3\text{PO}_4}\right) = \text{moles of precipitate}$$

E. Using the balanced chemical equation, convert the moles of $Co(NO_3)_2$ to moles of precipitate:

$$\text{moles Co(NO}_3)_2 \times \left(\frac{\text{stoich. coeff. precipitate}}{\text{stoich. coeff. Co(NO}_3)_2}\right) = \text{moles of precipitate}$$

F. What is the limiting reagent and what is the theoretical yield (moles) of precipitate?

G. Calculate the molar mass of the precipitate:

Note: The precipitate formed in this experiment is actually a hydrate!

precipitate • X H_2O

Do some literature research to determine the most common hydrate of the precipitate, and then, based upon your answer, calculate the correct molar mass of your precipitate.

H. Convert the theoretical yield (moles) of precipitate to grams:

$$\text{thoretical yield (g)} = \text{theoretical yield (moles)} \times \left(\text{molar mass of precipitate} \bullet \text{X H}_2\text{O, g/mole}\right)$$

I. Calculate the percent yield of the reaction:

$$\%\ \text{yield} = \frac{\text{step } \mathbf{A}}{\text{step } \mathbf{H}} \times 100$$