Determining the Phosphorus Content in Plant Food

Plant foods and fertilizers are commonly characterized by three numbers: 1) mass percent nitrogen; 2) mass percent phosphorus (as P_2O_5); and 3) and percent potassium (as K_2O). In this experiment, we will check the number corresponding to the "phosphorus" content.

P_2O_5 is the **acidic anhydride** of H_3PO_4, commonly known as phosphoric acid; this acid has the phosphate ion, PO_4^{3-}, as its anion. An acidic anhydride is derived from dehydration of the corresponding acid. Conversely, mixing an anhydride with water will give the corresponding acid. The equilibrium that exists is shown in Equation 1. As shown, the reaction is unbalanced. You will balance this equation as part of the pre-lab assignment.

+ H_2O

phosphoric acid, H_3PO_4 "P_2O_5"

Equation 1

Consequently, when a plant food is dissolved in water, the phosphorous-containing species is converted to something more like H_3PO_4 than P_2O_5. We don't say that the species is H_3PO_4 because in solutions that have a range of acidities, the actual species in solution could be H_3PO_4, $H_2PO_4^{-}$, HPO_4^{2-}, or PO_4^{3-}, with more acidic solutions favoring the **protonated** (i.e., H^+ containing) species, and more basic solutions favoring the **deprotonated** (without H^+) species. In the slight acidities and basicities experienced in this experiment, we will actually be dealing with HPO_4^{2-}, and we will utilize a property of these ions that will allow us to **precipitate** them and thereby separate them from solution.

Gravimetric analysis is a technique that involves selectively precipitating an analyte and then weighing the precipitate to determine how much analyte is present. The solid precipitate is separated from the surrounding solution by filtration. For instance, chloride might be determined by adding silver (I) (Ag^+) ions and weighing the resulting AgCl precipitate. Because one silver ion precipitates one chloride ion, the number of moles of AgCl will be exactly equal to the number of moles of chloride ion in the original solution.

In general, the key to gravimetric analysis is having components in two or more solutions which, when mixed together, will react to form an insoluble product that precipitates. In this experiment, one solution will contain the plant food for which we hope to determine the amount of phosphorous-containing ions. The second solution will contain aqueous magnesium ions,

Mg^{2+}(aq). The final solution will consist of aqueous ammonia. When the three solutions are mixed, $MgNH_4PO_4 \bullet 6H_2O$ will precipitate, as shown below in Equation 2.

$$Mg^{2+}(aq) + NH_3(aq) + HPO_4^{2-}(aq) + 6\ H_2O(l) \rightarrow MgNH_4PO_4 \bullet 6H_2O(s) \quad \textbf{(Equation 2)}$$

The compound that is produced, $NH_4MgPO_4 \cdot 6H_2O$, is called ammonium magnesium phosphate hexahydrate. As a solid mineral, it has another name, struvite. It is what we call a double salt, as it contains two different cations (NH_4^+ and Mg^{2+}). The hexahydrate indicates that when this ionic compound crystallizes, it incorporates 6 moles of water into the structure for each mole of NH_4MgPO_4. This is important since the mass of the water must be included when determining its molar mass. Struvite is a common component of bladder and kidney stones in both humans and cats.

In order to use this information to determine the amount of phosphorus (as P_2O_5), it is necessary to precipitate and carefully mass $MgNH_4PO_4 \bullet 6H_2O$ from a known quantity of plant food. Then, the balanced chemical equations can be used to back-track from the mass of the precipitate to the mass of the P_2O_5. This will involve several conversions of mass to moles and moles to mass.

The difficult part of this experiment is in controlling the acidity of the solution so that the only phosphate species that forms is the HPO_4^{2-} ion. If the solution becomes too basic, there will be PO_4^{3-} rather than HPO_4^{2-} and none of the desired precipitate will form. Additionally, if the solution is sufficiently basic, hydroxide ions will precipitate with Mg^{2+} to form $Mg(OH)_2$. However, if the solution is not basic enough, $H_2PO_4^-$ will be formed, and no precipitate will occur.

To control the basicity, slowly add ammonia until the initial precipitation is complete. Adding too much or too fast can lead to the co-precipitation of $Mg(OH)_2$.

OBJECTIVES

In this experiment, you will

- Determine the amount of phosphorus (as P_2O_5) in a commercial plant food
- Apply gravimetric analysis techniques

AP Chem Learning Objectives: SPQ-2.A.2, SPQ-2A.3, SPQ-2.B.1, SPQ-2.B.2, TRA-1.A.2, SPQ-4.A.1, SPQ-4.A.2; Science Practices 2.A, 2.C, 2.D, 2.E, 2.F, 5.F, 6.D, 6.F, 6.G

MATERIALS

Isopropanol solution (70% m/m)	600 mL beaker
Distilled water	Weighing paper
10% (m/v) magnesium sulfate, $MgSO_4$	Precise balance
2 M ammonia water	Ring stand
Stirring rod with rubber policeman	Ring
Commercial plant food	Spatula
Funnel	Scoopula

SAFETY PRECAUTIONS

Do not smell the ammonia solution and be careful to not spill any on your skin. Aqueous ammonia is corrosive to skin and eyes. If any of the reagents in this lab are spilled on your skin, wash the affected area copiously with water. If the ammonia vapor irritates the eyes, either rinse the eyes with the eye wash and/or step out of the lab until relieved.

PROCEDURE

1. Obtain and wear goggles.
2. Obtain a small sample of commercial plant food (about 1 gram). Determine the mass of the plant food sample and record this in your data table.
3. Transfer the plant food sample into a 150 mL beaker.
4. Add 15 mL distilled water to the beaker. Stir vigorously to dissolve. You may use a glass stirring rod to crush the solid and stir the mixture. Note: Once you put the stirring rod in the solution, you should leave it in the solution. If you remove it, any liquid (containing phosphate ions) adhering to the rod will be lost.

   Depending on the specific type of plant food, the solution may still appear cloudy at this point, and there may be a few small particles that do not dissolve. However, trying to filter them out would potentially introduce even more issues! So do your best to get them to dissolve, but continue even if they don't completely dissolve.
5. Add 15 mL of 10% $MgSO_4$ to the filtrate and stir the sample.
6. While stirring, slowly (over the course of about a minute) add 15 mL of 1 M ammonia water to the plant food sample. If no solid forms, try adding more ammonia solution and then consult with your instructor if no precipitate formation is observed.
7. Let the mixture sit for 10 minutes to allow the reaction to go to completion.
8. Set up a funnel and ring stand as shown in Figure 1. Place a 400 mL beaker under the funnel.

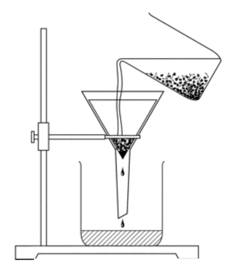


Figure 1

9. Write your initials in pencil on a piece of filter paper. Record the mass of the filter paper. Place the filter paper in the funnel.
10. Transfer the reaction mixture to the filter paper and collect the precipitate by gravity filtration. *(Be patient: the filtration process takes some time! You may need to let the filtration apparatus sit overnight.)*
11. Rinse the beaker reaction beaker with about 10—15 mL distilled water and use this rinse to wash the precipitate in the filter apparatus. Repeat twice more.
12. Wash the precipitate with 10 mL of isopropyl alcohol.
13. Remove the filter paper from the funnel and set it on a clean plate or watch glass and allow the sample to dry overnight.
14. Determine the mass of the filter paper with the precipitate and record this value in your data table.
15. Share data with classmates so that everyone has data from at least 3 "good" trials.

DATA TABLE

Name of Plant Food: ______________ Percent Phosphorus (from plant food label) ________________

	Trial 1	Trial 2	Trial 3
Mass of plant food (g)			
Mass of filter paper (g)			
Mass of filter paper and precipitate (g)			

DATA ANALYSIS

1. Calculate the mass of the precipitate formed.
2. Calculate the grams of P_2O_5 in the original sample.
3. Calculate the percent of P_2O_5 in the original sample.
4. Find the average percent P_2O_5 from the three trials.
5. For each trial, determine the percent error.

In your lab report, include the worked-out calculations for trial 1. (It is acceptable to hand-write them into your report. If you want to be fancy, try the MS Word equation editor.)

DISCUSSION

1. Why do plant food manufacturers add a phosphorus compound to the product?
2. Why is it necessary to wash the precipitate?
3. If a student added the ammonia solution too quickly, resulting in the co-precipitation of $Mg(OH)_2$, how will the experimental % P_2O_5 of be affected? Justify your answer using quantitative reasoning.
4. Based on your results, how closely does the mass percent correspond to the percent stated on the packaging? Does it seem that manufacturers put a little more, a little less, or close to the advertised amount of “phosphorous” in their products?

Remember to include the conclusion, works cited and further investigation portions of the lab report!

Prelab Assignment

Answer these questions in your lab notebook.

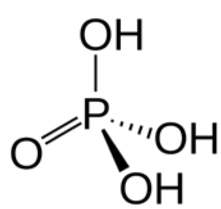
1. What is gravimetric analysis?
2. Is there any other ion besides Mg^{2+} that could be used to selectively precipitate the phosphate ions along with ammonium ions? Explain your answer.
3. **Acidic anhydrides** react with water to form acids; they are significant contributors to acid rain. Typically, they are non-metal oxides. **Basic anhydrides**, usually metal oxides, react with water to produce bases. Identify the following substances as acidic or basic anhydrides. Name the compounds to practice nomenclature.

Formula	Acidic or basic anhydride?	Name
CaO		
CO		
SO_2		
Li_2O		

4. In order to construct acid or base molecules from anhydrides, simply be creative in adding one or two or perhaps three water molecules to the anhydride—whatever it takes to produce a common molecule. When producing an anhydride from an acid or base molecule, literally subtract 2 H's and 1 O atom from the formula. If a common oxide does not result, then do that subtraction from the sum of two original molecules.

   a) What is the anhydride of $Ba(OH)_2$?
   b) What is the result if N_2O_3 is bubbled through water? Write an equation as part of your answer.
   c) Write a balanced equation showing the dehydration of phosphoric acid, H_3PO_4, to form its acidic anhydride, P_2O_5.

Phosphoric acid



Finally, set up your lab notebook—make sure the procedure and data tables are ready to use and that your table of contents is up to date.