EXPERIMENT 25 THE FERTILIZER PROJECT—ANALYSIS OF PHOSPHORUS IN FERTILIZER

INTRODUCTION

In this project we will investigate the phosphorus content of soluble fertilizers. The idea is to simulate the type of problem that might be solved in a real job situation. The scenario is that an analytical company has been hired to evaluate the phosphate content of water-soluble plant fertilizers. A decision must be made about how to do the analysis. You are part of a team in this company who has been assigned the task of developing the method needed to perform this analysis.

Typically, the steps in developing a method for a specific type of analysis are as follows:

- The scientific literature is researched to find similar types of analyses—ones that analyze for the phosphate content of samples that aren't necessarily fertilizers. These are referred to as **standard procedures**. Two procedures that analyze the phosphate content of the salt KH₂PO₄ are given in this handout.
- 2) The published procedures are modified to specifically analyze the material of interest—in this case, fertilizer. Modifications include determining how much of the fertilizer sample to use in the analysis, and whether any unique properties of the fertilizer (presence of insoluble impurities, color) will interfere with the published procedure.
- 3) After a number of analyses have been performed using the different published procedures, the data is analyzed, and a decision is made as to which procedure is most appropriate. Some considerations in the choice will be: the ability of inexperienced lab technicians to execute the procedures reliably in a reasonable amount of time, the reproducibility (precision) of the results obtained, the accuracy of the results obtained, the cost of the reagents and equipment required, and the ease of disposing of any waste generated in the analysis. One way to make such a decision would be to establish a team to make a recommendation, and that is what we shall do here.

PROCEDURE

Each team will consist of four members with assigned roles. The **team leader** does just what the name suggests—organizes the tasks, assigns equivalent work to each team member (including him/herself). The **recorder** keeps a systematic record of the results provided by each team member and the conclusions of discussions reached. The **assistant team leader** assembles the final group report to be submitted. The **information coordinator** is responsible for formulating questions to be asked of the instructor, obtaining the answers and conveying the information obtained to the other team members.

At the start of the project each team will develop two protocols—one for a **gravimetric** analysis of the fertilizer and one for a **spectrophotometric** analysis. A preliminary version of each protocol will be submitted and returned for revision after suggestions from the instructor. The final versions of the protocols will be submitted one lab period after receiving the preliminary protocol back from the instructor. Each

team member will receive a score *only for the protocol they worked on*, which will be twenty percent (20%) of each person's total grade for the project. At the end of the project, each team member will write an individual report using his/her own data and the shared data of team members to recommend one of the analytical methods; seventy percent (70%) of the grade will be based on this report. The report will also include an introductory essay on the environmental significance of phosphates, which will be written and researched as a team. Ten percent (10%) of the grade will be based on an evaluation of each team member's contribution to the project, both by the TA and the other team members.

Fertilizers contain nutrients required by plants. Among these are the elements N, P (reported as P₂O₅) and K (reported as K₂O). The composition is reported on the container as three numbers such as 13-13-13, which means that the formulation contains 13% by weight N, 13% by weight P₂O₅ and 13% by weight K₂O. Even though fertilizers do not actually contain P₂O₅ (which would react violently with water) or K₂O, it is customary for historical reasons to report the content in this way. In fact, P is generally present in fertilizers as the phosphate ion PO₄³⁻. Many products are over formulated; that is, they contain more of some ingredient than is promised on the label. Also, the content of a particular sample may vary as much as $\pm 0.5\%$ because of the problem of achieving complete homogeneity in the mixing of solids. Thus, in evaluating analytical procedures, the agreement among large numbers of results is more important than obtaining the exact percentage on the label (unless the result obtained is ridiculously different).

Each team of four will be assigned one brand of commercially available plant food and asked to determine the percent P_2O_5 by two different standard procedures. Before reporting your results for use by other members of the group, you need to be sure that your own technique is good enough to achieve reliable numbers. This means that each team member will need to do the analysis until two successive results agree within 1.5% of the value of the quantity being measured. For example, if two determinations find 12.51 and 12.91% P_2O_5 , these agree within 0.40% in 12.71% (the average value), or to within 3.1%. Hence, another measurement would be in order.

Two types of analytical methods will be used. In **spectrophotometric analysis** the substance of interest (in our case phosphate, PO_4^{3-}) is converted to a colored compound. The intensity of the color produced can be measured and is proportional to the amount of phosphate present. In **gravimetric analysis** phosphate is precipitated as an insoluble compound which can then be weighed. The standard methods for analysis are described in **APPENDICES 25B** and **25C**.

WHAT EACH TEAM AND TEAM MEMBER IS EXPECTED TO DO

The **team** is responsible for the following:

- Writing an essay of about 500 words detailing the environmental significance of phosphate. APPENDIX
 A gives some suggestions for researching this essay via the Internet.
- 2. Developing a set of directions (a protocol) for analyzing the fertilizer sample. Two team members will develop a protocol for the gravimetric procedure and the other two for the colorimetric procedure; *only one protocol for each method should be submitted*. The intent of the protocol is to provide detailed information for someone to 1) perform the procedure and 2) do the necessary calculations to determine the %P₂O₅ in the fertilizer sample (typically, a lab technician with limited chemical knowledge is assigned to perform the analysis). The protocol should be typed (the calculations may be written by hand).

Protocol procedure: You will be using the procedures given in **APPENDICES B** and **C** as a basis for your fertilizer procedure. Note that the procedures given are for the analysis of a known phosphate sample; much of your protocol procedure will be identical. However, when you get to the **Sample Analysis** portion of the procedure, **you will need to modify each procedure to analyze for fertilizer, rather than the known sample**. Some ideas on how to modify the procedure are given in the **Protocol Considerations** section after each procedure.

Sample calculations to be included in the protocol are given below:

Gravimetric method:

- The amount of fertilizer sample needed for the analysis
- The mass of phosphorus atoms present in the Mg(NH₄)PO₄·6H₂O product
- The percent of P_2O_5 in the fertilizer sample

Spectrophotometric method:

- the concentration of PO_4^{3-} in any one of the solutions used to generate the calibration curve;
- how the fertilizer sample is diluted to the desired concentration (the mass of fertilizer to be weighed out);
- the mass of P in the fertilizer sample solution;
- the % of P_2O_5 in the original fertilizer sample.

Note that these calculations will not include actual measured data, but simply show how the calculations are set up.

The preliminary versions of these protocols will be turned in; your TA will make comments and return them to the team for revision.

Each team member is expected to:

- 1. Execute tasks in designing protocols and researching the essay as assigned by the team leader.
- 2. Give legible copies of all results to the team recorder.
- 3. Make at least two determinations of the % phosphate in a pure sample of known phosphate content (KH₂PO₄) and in the sample of commercial fertilizer by the method for which he/she helped develop the protocol.
- 4. Teach this method to a team member who developed the other protocol and help him/her make measurements as in 3.
- 5. Learn the second analytical method from a team member and make measurements as in 3.
- 6. Share the results with all other team members. This will give a total of eight measurements for the fertilizer sample and four for the known phosphate sample for each procedure—two from each team member—as well as four for the known phosphate sample for each procedure. Ideally, the measurements in 3 and 5 should all agree with one another within 1.5% of the quantity being measured. If they do not, some decision as to why must be made. Does one person's data seem out of line? If so, what is the problem? Measurements may need to be repeated until each person is satisfied that accurate results are being obtained through improved lab technique as a result of practice. (This is important

because one needs to choose procedures that will give the same results no matter which lab tech does the analysis.)

- 7. Write a report which
 - a. incorporates your essay as part of the **INTRODUCTION**;
 - b. presents your protocols as the **PROCEDURE** section.

c. gives data sets obtained and the results in the **DATA** and **RESULTS** section. Each data set is to be labeled with the name of the person who obtained it, and all data obtained are to be presented;

d. discusses which (if any) sets of data are to be excluded from the analysis and why.

e. evaluates the two analytical methods based on criteria mentioned above. If the results of the two methods are different from one another (for example, the gravimetric method consistently gives around 30.2% phosphate while the colorimetric method consistently gives around 31.8% phosphate) a discussion of the reasons why should be given.

8. Evaluate on a scale of 1 (worst) to 10 (best) the contribution by the other three team members using the form provided later in the quarter.

The Time Line

First Lab Period (Introduction)—

Form teams and assign roles. Determine which team members will work on the protocols for the two methods. Begin research on the essay.

Second Lab Period—

Draft protocol for project due

Begin analysis of KH₂PO₄

a. One or two members perform the colorimetric analysis (see APPENDIX B).

b. Two team members each do the gravimetric analysis (see APPENDIX C).

Third Lab Period—

Team members discuss progress with TA

Teams will go over last period's results; TA will comment on protocols.

Begin analysis of fertilizer

Each team member does the same analysis as last lab period, except now analyzing for phosphate in **fertilizer** rather than the KH₂PO₄.

Fourth Lab Period—

Final protocol for project due

Team members discuss progress with TA

Switch Methods for analysis of fertilizer

Team members teach analysis methods to each other.

APPENDIX 25A: DOING RESEARCH VIA THE INTERNET

The Internet has available **search engines** such as Yahoo, Infoseek, Altavista, etc. Each search engine offers directions for executing a search on given topics. In general, you supply key words; the more you supply, the more you narrow the search. Here, you might use at least three key words such as: phosphate, fertilizer, environment or phosphate, water, environment. The search engine brings up hits, which you can examine and read one by one to determine their usefulness.

APPENDIX 25B: SPECTROPHOTOMETRIC ANALYSIS

In a spectrophotometric analysis, the element of interest is incorporated into a colored compound which remains dissolved in solution. The intensity of the color (and consequently the amount of light absorbed) is related to the amount of the element present by the equation $A = \varepsilon bC$.

It is usually a good idea to experimentally determine the relation between *A* and *C*. The procedure for doing this consists of preparing several solutions having different known concentrations *C* of the colored compound and measuring *A* for each one. A plot of absorbance *A* versus *C* gives a so-called **calibration curve** relating *A* and *C*. If one now takes a solution of unknown concentration and measures *A*, its concentration can be read from the curve. Beer's Law suggests that the calibration curve should be a straight line which passes through the origin (A = 0 when the concentration of the colored compound C = 0) having slope εb . Actually preparing a calibration curve takes into account any minor deviations from Beer's Law.

Activity Chart for Spectrophotometric Analysis

Prepare Calibration Curve Obtain 5.00 x 10⁻³M PO₄³⁻ stock solution Dilute 3mL of stock solution to 250mL to make . working solution Prepare colored solutions containing 1.0, 2.0, 3.0, 4.0 and 5.0mL of the working solution and 4 mL of heteropoly blue solution diluted to 10 mL Obtain and save absorbance spectra for each colored solution Print compiled spectra and obtain absorbance values using Absorbance Series program Calculate $[PO_4^{3-}]$ for each colored solution and plot A vs. [PO₄^{3–}] using Beer' Law Plot subroutine in Absorbance Series program **Obtain Sample Spectra** Weigh out sample (KH₂PO₄ 1st lab period; • fertilizer 2nd and 3rd periods) Dissolve sample in 250 mL water to make ٠ sample solution Dilute 3mL of sample solution to 250mL to . make working solution Prepare colored solutions containing various aliquots of the working solution and 4 mL of heteropoly blue solution diluted to 10 mL Obtain and save absorbance spectra for each colored solution

• Print compiled spectra and obtain absorbance values using Absorbance Series program

To prepare a calibration curve, you need to take a solution having a known percent of P and prepare samples by dilution containing concentrations of P close to the ones you expect to encounter with your fertilizer. You will be provided with a **stock solution** of known PO_4^{3-} concentration. Solutions of lesser molarity can be prepared by pipetting out portions of this solution into smaller volumetric flasks and diluting them to the mark to create a **working solution**. Portions of the working solution are subjected to a procedure that develops a **colored solution** and *A* is read. A plot of *A* versus the molarity of the colored species establishes a relationship between a known amount of P and the solution Absorbance. (Your protocol should state what the relationship is.) Then, the fertilizer sample can be dissolved in 250 mL of water to make a **sample solution** and then diluted to a **working solution**; this solution is used to develop the colored compound and the quantity of P actually present in the fertilizer can be related to the concentration of P in the colored solution experimentally determined by *A*.

In this method, the phosphoric acid is converted into a "heteropoly blue" complex by adding it to a developing solution containing 2.5×10^{-3} M ammonium molybdate, 2.40×10^{-3} M ascorbic acid and 0.75 M H₂SO₄; the following reaction occurs:

$$7 \text{ PO}_{4}^{-} + 21 \text{ H}^{+} + 12 \text{ (NH}_{4}\text{)}_{6}\text{Mo}_{7}\text{O}_{24} \cdot 4\text{H}_{2}\text{O} \rightarrow$$

$$7 \text{ (NH}_{4}\text{)}_{3}[\text{PO}_{4}(\text{MoO}_{3})_{12}] + 51 \text{ NH}_{4}^{+} + 51 \text{ OH}^{-} + 33 \text{ H}_{2}\text{O}$$

$$(25-1)$$

The molybdophosphate product (which contains Mo(VI)) is colorless. This compound is reduced by ascorbic acid to a blue compound containing Mo(V) and Mo(VI). The developing solution is made up so that there is an excess of both molybdate and ascorbic acid large enough to convert all of the phosphoric acid in any of the solutions you will prepare. (That is, PO_4^{3-} is the limiting reagent in all your solutions.)

Standard Procedures for Spectrophotometric Analysis

Heteropoly Blue Method (*Colorimetric Determination of Nonmetals*, D. F. Boltz, Ed., Interscience, New York, 1958. p. 32)

EQUIPMENT NEEDED

cuvets (2) 50 mL beaker 10 mL volumetric flask (1) 250 mL volumetric flask 5 mL Mohr (graduated) pipet 5 mL volumetric pipet graduated disposable pipets MeasureNet spectrometer Medium test tubes **CHEMICALS NEEDED** 5.00 x 10-3 M PO₄³⁻ solution Heteropoly blue developing solution KH₂PO₄ (1st lab period)

Fertilizer (2nd lab period)

Constructing the Calibration Curve

Note: you must construct a new calibration curve at the beginning of each laboratory period.

- 1. A standard stock solution containing $5.00 \times 10^{-3} \text{ M PO}_4^{3-}$ will be provided. Obtain ~20 mL of the stock solution in a clean dry 50-mL beaker. (Why must the beaker be dry?)
- 2. Use a Mohr pipet to deliver 3.00 mL of this solution into a 250-mL volumetric flask and dilute to the mark with water. Mix the solution thoroughly by inverting the flask several times. This is your **working solution**. Determine the concentration of this solution.
- 3. Use a volumetric pipet to deliver 5.00 mL of your working solution into a 10-mL volumetric flask; use a disposable pipet to add ~4 mL of developing solution (since this reagent is in excess, the volume needed is approximate--you can use the volume markings on the barrel of the pipet) (CAUTION! The developing solution contains acid.). Dilute to the mark with distilled water and mix. This is one of your colored solutions. Pour the solution into a labeled medium test tube. Rinse the volumetric flask thoroughly with distilled water.
- 4. Prepare four more **colored solutions** by repeating the procedure in step 3, starting with 4.00, 3.00, 2.00 and 1.00 mL of the working solution. Pour each solution into a separate medium test tube, making sure each is labeled carefully.
- 5. A so-called **reagent blank** must also be prepared in case any other constituents of the solution besides the blue one might also contribute to the absorbance at the selected wavelength, as well as correcting for any residual PO₄³⁻ present in the distilled water. This reagent blank can be used as the reference solution when obtaining the absorption spectra. To do this, add 4 mL of developing solution to the 10-mL volumetric flask and dilute to the mark with distilled water. Pour this solution into another labeled medium test tube.
- 6. Place the test tubes in a boiling water bath for 10 minutes to develop the blue color. Cool each test tube to room temperature under a stream of water. Carefully tilt each test tube so that the solution mixes with the water that has condensed on the inside of the test tube.
- 7. Set up the MeasureNet workstation by pressing the MAIN MENU button. (Make a note of your workstation number- you will need it at the spectrometer.) Select SPECTROSCOPY, then ABSORPTION(1), then DISPLAY. Do not change any of the other graphing limits. Fill one cuvet with one of the colored solutions, and fill another cuvet with the reagent blank solution. Take the cuvets to the spectrometer.
- 8. At the spectrometer, press **STATION NUMBER**, then your station number, then **ENTER**. Place the reference cuvet (containing the reagent blank solution) snugly in the sample holder, making sure that the arrow on the cuvet is facing toward the light source. Block the light path by placing the flat object provided in the slot beside the cuvet, and press **ZERO** on the spectrometer. Remove the object blocking the light, then press **REFERENCE** on the spectrometer.
- 9. Remove the reference cuvet from the sample holder and replace it with the sample cuvet (containing the colored solution), making sure it is aligned properly. Press **SAMPLE** on the spectrometer. Remove the cuvet and return to your workstation.
- When the absorption spectrum appears on the screen, press FILE OPTIONS then select SAVE to save the data to a file on the computer. Enter a three-digit file code for the spectrum and then press ENTER.
 Note: Keep a careful record in your notebook of the file numbers you use and the solutions to

which they apply. Do not print anything until you have obtained and saved spectra for all of your solutions.

- 11. Obtain and save absorption spectra for each of the remaining colored solutions by repeating steps 7-9. Note: for best results, use the same cuvet for each of your colored solutions. Rinse the cuvet with a small amount of the next solution to be measured before filling it in preparation for the next spectrum. Use a different three-digit file code for each spectrum.
- 12. Use the software "Absorbance Series" to plot your spectra, all in one graph. Examine your plotted data on the computer screen. If any of the spectra need to be remeasured (non-zero baselines, etc.), repeat the measurement and save the new absorption spectrum with the same file number used the first time. Then replot your spectra using "Absorbance Series." After you have determined the wavelength you will use for analysis, print the plot. You will then select 'Beer's Law Plot" from the "Analysis" menu and enter the appropriate absorbance values and concentrations of phosphate for each **colored solution**. The resulting Beer's Law plot will be your calibration curve of *A* vs. concentration of "heteropoly blue" (in mol/L). Since **EQUATION 25-1** shows an equimolar relationship between phosphate ion and the "heteropoly blue" species, **your calibration curve also represents a plot of A vs.** [**PO**₄³⁻]. Note that the linear regression line passes through the point (0,0). (That is, A=0 when [PO4³⁻] = 0.) If any of the points deviate greatly from the rest of the data, you should remeasure the spectrum for that point and repeat the analysis.

Sample Analysis

- 13. Using solid KH₂PO₄, prepare 250mL of a known phosphate sample solution containing a PO₄³⁻ concentration similar to that of the standard stock solution. Determine the amount of KH₂PO₄ needed to make 250 mL of this solution *before* you come to lab. Add 3.00 mL of this solution to another 250 mL volumetric flask as in step 2 to make a working solution, then prepare three colored solutions as in step 3, using different aliquots (volumes) of this solution. Prepare another reagent blank solution to serve as a reference as in step 5. Record and save the absorption spectrum for each of these solutions, being careful to keep an accurate record of the file names you use and the solutions to which they apply. To determine the absorbance for each of these solutions at the wavelength you chose for the calibration curve, plot and print the spectra using "Absorbance Series" as above. You do not need to generate a Beer's Law plot for the sample data.
- 14. Rinse all glassware thoroughly with distilled water before returning.
- 15. Using the equation for the linear regression line on your calibration curve, determine the [P] in the colored sample containing the known phosphate solution you prepared. You can assume that there is one PO_4^{3-} in each heteropoly blue formula unit; hence, $[P] = [PO_4^{3-}] = ["heteropoly blue"]$. Determine [P] in the working solution, then in the original prepared solution. Convert this value to %P₂O₅. How does this value compare to the expected %P₂O₅ of this solution?

Protocol Considerations

When you develop the protocol for the fertilizer, you need to weigh out an amount of fertilizer that will provide a quantity of P comparable to what was used in determining the calibration curve. As an estimate, we will assume that the fertilizer will contain approximately 18% P; you can use that approximation to **calculate the approximate mass of solid fertilizer needed** to make 250 mL of **sample solution** that has a concentration similar to that of the PO_4^{3-} stock solution; that is, ~5 x 10⁻³ M.

You should dissolve the solid in ~50 mL water and gravity filter it to remove insoluble substances, then add the **entire** filtrate to the 250 mL volumetric flask and add water to the final volume of 250 mL. Don't forget to dilute this sample solution by 3 mL/250mL to prepare the **working sample solution** before developing the colored solutions.

For preparing the colored solution, select a volume of your working sample solution that will give an absorbance reading in the range of your calibration curve (usually between 1 and 5 mL).

Also, since the fertilizer may itself be colored with dye and so contribute to the Absorbance at the wavelength of measurement, the reagent blank should be prepared by adding 3 mL of the working fertilizer sample solution to the 10mL volumetric and diluting to the mark with water. Do not add the developing solution to the reagent blank solution.

In interpreting the concentration measurements on your fertilizer sample, keep in mind that you wish to convert the concentration of the solution to a certain number of g of P in the original sample. This number of g of P is equivalent to some number of g of P_2O_5 . You need to show how to make this conversion in your protocol.

APPENDIX 25C: GRAVIMETRIC ANALYSIS

In a gravimetric analysis, the element of interest is incorporated into an insoluble compound which precipitates from the solution and can be weighed. Since the identity of the insoluble compound is known, the per cent composition can be calculated and the number of grams of the element calculated. For example, insoluble AgCl is composed of 24.75% Cl and 75.24% Ag; so for every 1.000 g of AgCl precipitated from a solution, the solution must have contained 0.2475 g Cl-. Knowing the weight of the element contained in the original sample, allows one to calculate what per cent of the original weight the element contributes. Obviously, the original sample must be dry since any unknown amount of water in the sample will contribute to the original weight taken and thus throw off the percent P_2O_5 determined. (*How?*)

Once the sample has been dissolved, you must take care that absolutely none of the solution is spilled or allowed to remain behind in a beaker, on filter paper, etc.; otherwise, an unknown amount of phosphate will be lost. Thus, it is important to rinse out flasks and to wash filter paper and to put the rinsings and washing back into the sample-containing solution.

Standard Procedure for Gravimetric Analysis

Magnesium Ammonium Phosphate Method (Solomon, S.; Lee, A. and Bates, D. J. Chem. Ed., 1993, 5, 410)

$$6 H_2O + PO_4^{3-} + Mg^{2+} + NH_4^+ \rightarrow Mg(NH_4)PO_4 \cdot 6H_2O_{(s)}$$
(25-2)

EQUIPMENT NEEDED

50 mL beaker 10 mL graduated cylinder 250 mL suction flask Büchner funnel watch glass

CHEMICALS NEEDED

0.4 M MgSO₄ solution

red litmus paper filter paper graduated disposable pipet vacuum tubing

KH₂PO₄ (1st lab period)

6M NH₃

Fertilizer (2nd lab period)

PROCEDURE

Weigh out enough KH₂PO₄ sample to contain about 0.1 ± 0.01 g of P. Have this mass calculated *before* coming to lab.

Dissolve the sample in about 10 mL of deionized water in a 50 mL beaker. (*Does the exact volume make a difference? Why or why not?*)

Add 10 mL of the 0.4 M MgSO₄ solution. Using a disposable plastic pipet, *slowly* add 1 mL 6M NH₃ dropwise while stirring. This will precipitate insoluble Mg(NH₄)PO₄·6H₂O. After adding all of the NH₃, touch the stirring rod to a piece of red litmus paper. Repeat this, adding 1 mL of NH₃ at a time, until the litmus turns blue when the solution contacts it. Then add a few drops more of NH₃. (why do we do the litmus test?) Let the solution stand about 15 min to complete the precipitation. Filter off the precipitate using suction filtration. Wash the precipitate with two 5-mL portions if *iso*-propyl alcohol. (This helps the precipitate dry faster; the alcohol dissolves any water remaining on the precipitate and evaporates very rapidly.) Suck air through the filter for about twenty minutes to help dry the precipitate. Let the precipitate dry in air for half an hour and weigh the watch glass with precipitate. If your precipitate is not dry, the weight will continue to change with time. (*Will it get lighter or heavier? Why?*)

While you are waiting for the product to dry, perform a second trial by the previous steps.

Measure the mass of the product, and use this to determine the % P₂O₅ in the sample.

Protocol Considerations

In formulating your protocol, consider what kind of balance you want to use for your measurements. Ideally, you should have at lease three significant figures in your final percent P_2O_5 .

As an estimate, we will assume that the fertilizer will contain approximately 18% P; you can use that approximation to **calculate the approximate mass of solid fertilizer needed.**

When you formulate the protocol for the fertilizer analysis, you should also filter the dissolved sample by gravity to remove any insoluble impurities (be sure to rinse the filter paper with distilled water and add the rinsing to the filtrate). (*How would insoluble substances affect the result?*)

Show how you will use the mass of $Mg(NH_4)PO_4 \cdot 6H_2O$ formed to calculate the percent P_2O_5 in the original sample.