Thermodynamics and Solubility of Calcium Hydroxide

We usually view thermodynamics and equilibrium chemistry as providing different information about a chemical reaction. For example, with thermodynamics we ask *Is this reaction likely to occur?*, calculate ΔG, and make a prediction; with equilibrium chemistry, however, we ask *What is the composition of this reaction mixture at equilibrium?*, and use the reaction's equilibrium constant, K_{eq} and initial composition to make a prediction. What is hidden in these questions is the mathematical relationship $\Delta G^o = -RT\ln K_{eq}$ that ties together these two views of chemical reactivity; thus, we can use a reaction's equilibrium constant and the reaction mixture's reactant quotient, Q, to predict the favorable direction for a reaction, and we can use the free energy at any time during the reaction's progress to determine the reaction's composition at that moment. The purpose of this two-week, open-ended project is to study the solubility reaction $\mathrm{Ca(OH)_2}(s) \rightleftharpoons \mathrm{Ca^{2+}}(aq) + 2\mathrm{OH^-}(aq)$ for which the equilibrium constant is $K_{sp} = [\mathrm{Ca^{2+}}][\mathrm{OH^-}]^2$. More specifically, you should design and carry out suitable experiments that can provide answers to the following questions:

- How does the solubility of $\mathrm{Ca(OH)_2}$ change with temperature?
- What are the values of ΔG^o, ΔH^o, and ΔS^o for the solubility of $\mathrm{Ca(OH)_2}$?

Preparing for Lab

Planning for this lab is critical to your success. Be sure to complete the relevant sections of your notebook before each week's lab session. As you develop strategies for determining values ΔG^o, ΔH^o, and ΔS^o, keep the following in mind:

- Because the solubility reaction releases a base, $\mathrm{OH^-}$, you can use an acid-base titration to determine the concentration of $\mathrm{OH^-}$ in a saturated solution of $\mathrm{Ca(OH)_2}$.
- To determine the concentration of $\mathrm{OH^-}$ in a saturated solution of $\mathrm{Ca(OH)_2}$ you must first remove any undissolved $\mathrm{Ca(OH)_2}$ by filtering. Consider why this is necessary and what complications might arise if you don't successfully remove all the $\mathrm{Ca(OH)_2}$.
- To determine the concentration of $\mathrm{OH^-}$ in a saturated solution of $\mathrm{Ca(OH)_2}$ you will need a solution of HCl with a nominal concentration of 0.01 M. You will need to determine how to prepare this solution using the available stock solution of 1 M HCl. You will determine this solution's concentration by titrating it against the standard weak base tris(hydroxymethyl)aminomethane, $(\mathrm{HOCH_2})_3\mathrm{CNH_2}$, which also is called TRIS or THAM; you may take the reaction to be

$$\mathrm{TRIS}(aq) + \mathrm{HCl}(aq) \rightarrow \mathrm{TRISH^+}(aq) + \mathrm{Cl^-}(aq)$$

- Review your preparation and standardization of a standard solution of NaOH in the third preliminary experiment and adapt that procedure to this lab. Plan titrations that require ≈ 15 mL of titrant to reach the equivalence point. If your first titration requires significantly less than or significantly more than 15 mL, then adjust your procedure. To determine how much HCl to make, consider how many total titrations you will make in two weeks and assume each will require 30 mL of HCl; double this total and you will be fine.
- You need to decide how many mL of filtered $\mathrm{Ca(OH)_2}$ to use in your titrations. As a "rule of thumb," a room-temperature titration should use ≈ 15 mL of nominally 0.01 M HCl to reach the equivalence point. You might find it helpful to know that the solubility of $\mathrm{Ca(OH)_2}$ at 25°C is reported as one gram per liter of water. If your first titration requires significantly less than or significantly more than 15 mL, then adjust your procedure.
- You need to decide how to calculate ΔG^o using data from your titrations. Be sure you consider this before you begin gathering data so that you know the accuracy and precision needed for different measurements.
- It is possible to determine values for ΔH^o and ΔS^o by studying the solubility of $\mathrm{Ca(OH)_2}$ as a function of temperature; give some thought to how this is done.
- Experimentally determined values should be compared to their expected theoretical values.

Procedure

Your first task is to prepare and standardize your solution of HCl. Once this is completed you may begin to analyze samples. During the first week a room-temperature saturated solution of $Ca(OH)_2$ is available to you, which you can filter using gravity filtration. During the second week you will have access to a saturated solution of $Ca(OH)_2$ at elevated temperatures, which you can filter by syringe filtration.

Cautions

There are no cautions for this lab other than the normal respect for chemicals and hot solutions.

Waste Disposal

You may dispose of all solutions by rinsing them down the drain with copious amounts of water.

Lab Report

Remember to switch roles for this lab.

Role	Final Product	Responsibilities
Manager	formal report	organizes all aspects of the group's work both in and out of lab; makes all final decisions on experimental design; determines when sufficient work is complete
Chemist	short report	prepares solutions; weighs out samples; carries out the experiment
Technician	oral report	sets up, calibrates, and optimizes the group's equipment; maintains the group's electronic laboratory notebook

All group members must contribute to planning the experiment and to the analysis of data, and are responsible for understanding how to convert the experiment's data into results. Here are some details on the different types of reports:

- For the **formal** report you will present the results of your experimental work in the form of a journal article. For more details on the format of formal reports, review the document "Some Guidelines for Preparing a Formal Report," "Sample Report," and "Rubric for Evaluating Formal Reports" available at the course website. Although I will not formally review a draft of your report, I do encourage you to bring a draft of your report to my office with specific questions you wish to discuss.
- For the **short** report you will receive a set of data that is similar to that collected in lab along with some specific questions to answer using this data.
- For the **oral** report we will meet to discuss your group's work on this experiment. To prepare for this meeting, review your group's experimental plan, your group's data, and your group's analysis of that data. When you are ready, schedule a 30 minute meeting with me. This meeting should take place after your group has finished analyzing the data.