EQUILIBRIUM AND LE CHATELIER'S PRINCIPLE

Introduction

Le Chatelier discovered that placing a "stress" on a chemical system in equilibrium could shift the equilibrium position of a reversible reaction. The principle he developed to explain his observations is simple:

If a stress is placed upon a system in dynamic equilibrium, the system will adjust to relieve that stress.

If you understand how the stress will affect the system, then you can predict the changes that will take place in the system to relieve it. That is what you will do in this lab.

Cobalt forms compounds with both water and the chloride ion. Cobalt II, when in solution, does not exist by itself. Instead, it exists as a complex ion in which the cobalt atom is associated with six water molecules. This is the positive ion on the left side of the equation shown below. This positive ion has a **pink** color. In contrast, in the presence of substantial amounts of chlorine ions, the cobalt atom combines with four chlorine atoms and forms the negative ion on the right side of the equation shown below. This $CoCl_4^{2-}$ ion is **blue**. If both water and chloride ions are present in a solution with cobalt, then an equilibrium position will be reached between the two possible complexes, and the color will be along a continuum between blue and pink.

$$Co(H_2O)_6^{2+} + 4\ Cl^- \rightleftharpoons CoCl_4^{2-} + 6\ H_2O$$

You will be making several changes ("stressing the system") to a solution of cobalt chloride dissolved in water. Before each change, you will use Le Chatelier's principle to make a prediction about how the solution will adjust to relieve that stress. Following the change you make to the system, you will observe how the system adjusts to relieve the stress. This adjustment will be a shift in the equilibrium position of the solution, either toward the left (reactants) or toward the right (products). The change in the color of the solution will allow you to determine the direction and relative magnitude of the shift.

Please note that none of these are multiple choice questions. Each part must be answered in order to earn credit.

Pre-Lab Questions

1. In principle, all chemical reactions are reversible. Why is it that we are able to consider some of them as going to completion?

2. A reaction between nitrogen and hydrogen gases is shown below. It is reversible and should be shown with a double arrow. What should be the effect of each of the following changes on a constant-volume equilibrium mixture of N_2, H_2, and NH_3?

$$N_{2\,(g)} + 3\ H_{2\,(g)} \rightleftharpoons 2\ NH_{3\,(g)} + 92.38\ kJ \quad (\text{or } \Delta H = -92.38\ kJ)$$

a) adding H_2 (g)
b) removing NH_3 (g)
c) removing N_2 (g)
d) increasing the pressure
e) adding heat.

3. For the reaction below, what should be the effect of each of the following changes on a constant-volume equilibrium mixture of N_2O_4 and NO_2 be?

$$N_2O_{4\,(g)} \rightleftharpoons 2\ NO_{2\,(g)} \qquad \Delta H = +57.2\ kJ$$

a) adding N_2O_4 (g)
b) removing N_2O_4 (g)
c) adding NO_2 (g)
d) increasing the pressure
e) adding heat

4. For the reaction below, what should be the effect of each of the following changes on a constant-volume equilibrium mixture of all products and reactants?

$$4\ NH_{3\,(g)} + 3\ O_{2\,(g)} \rightleftharpoons 2\ N_{2\,(g)} + 6\ H_2O_{\,(l)} \qquad \Delta H = -1530.4\ kJ$$

a) decreasing the pressure
b) removing NH_3 (g)
c) adding N_2 (g)
d) removing $6H_2O$(l)
e) temperature drops

5. The reaction provided in the introduction yields an equilibrium mixture of a pink compound and a blue compound. Rewrite the balanced chemical equation and label the reactant and product side as either pink or blue according the information in the introduction. (This will be helpful to know for the lab analysis.)

Procedure

SAFETY 6.0 M HCl is corrosive, will cause burns and can permanently damage your eyes. Avoid skin contact when working with cobalt chloride crystals and solutions. Avoid inhalation of cobalt chloride.

1. Select 3 clean and dry test tubes of the same size and label them tubes 1, 2, and 3.
2. **Wear gloves.** To each test tube add approximately 0.20 g of cobalt chloride crystals. (Use weighing paper to mass each sample.)
3. Do the following:
   - To Tubes **1 and 3** add 1.0 ml of distilled water and stir. (This will become pink – reactants predominate, the $Co(H_2O)_6^{2+}$ ion is in abundance).
   - To Tube **2** add 1.0 ml of 6.0 M HCl and stir. (This will become blue – products predominate, the $CoCl_4^{2-}$ ion is in abundance).
   - Tubes 1 and 2 will be the standards that you use to estimate the equilibrium position for the solution in Tube 3.
4. ***Predict*** what happens (will it become more pink, more blue, or not change) if you add 5 ml of 6 M HCl to Tube 3.
5. Add 5 ml of 6 M HCl to Tube 3. ***Record*** the color change that occurs (if any).
6. If we assign the color in Tube 1 to be a "1", and the color in Tube 2 to be a "10", indicate a number between 1 and 10 that corresponds to the color currently in Tube 3.
   - Note that this is a scale between pink and blue, not a scale of lightness or darkness.
7. ***Predict*** what happens (will it become more pink, more blue, or not change) if you add 5 ml of distilled water to Tube 3.
8. Add 5 ml of distilled water to Tube 3. ***Record*** the color change that occurs (if any).
9. Using the same scale from step 6, indicate a number between 1 and 10 that corresponds to the color currently in Tube 3.
10. ***Predict*** what happens (will it become more pink, more blue, or not change) if the equilibrium solution is heated.
11. Fill a 400-ml beaker with 300 ml of tap water. Place Tube 3 into the water in the beaker and heat the beaker of water with a Bunsen burner until the water boils. Turn off the Bunsen burner. ***Record*** what happens with the color in Tube 3.
12. Using the same scale from step 6, indicate a number between 1 and 10 that corresponds to the color currently in Tube 3.
13. ***Infer*** from your observations whether the reaction is endothermic or exothermic.
14. ***Predict*** how the solution in Tube 3 will respond to being immersed in 0^oC water.
15. ***Record*** what happens with the color in Tube 3 when it is placed and cooled within an ice bath at 0^oC?
16. Dispose of all test tube waste in the provided waste beaker.
17. Clean all of your glassware in the sink and let these materials air dry on the counter.

Post-Lab Questions

6. In three cases during this lab, you made a prediction about how the equilibrium position of a solution would shift as a result of a stress placed on it. Explain each of these predictions.

7. If your prediction was incorrect in any of these cases, explain what actually took place and why.

8. Based on your data, was heat energy a reactant or a product in this reaction? Explain your reasoning.

9. For each of the four steps performed on Tube 3(add HCl, add H_2O, add heat, remove heat), explain your observations using LeChatelier's Principle.