Le Châtelier’s Principle

INTRODUCTION

Le Châtelier’s Principle states that when stress is placed on a system in equilibrium, the system will react to relieve the stress.

Stress refers to changes in concentration, pressure, volume, and temperature. Consider the exothermic chemical reaction:

\[ \text{SO}_2(g) + 0.5 \text{O}_2(g) \rightleftharpoons \text{SO}_3(g) \]

Concentration: If the reaction has reached equilibrium, and we disturb this reaction at equilibrium by adding \( \text{SO}_2 \), the added \( \text{SO}_2 \) would be reduced in quantity by the reaction moving to the right, forming more of the \( \text{SO}_3 \).

Pressure: For this reaction, an increase in pressure on the system would also move the reaction to the right. There are 1.5 total moles of gas on the left of the arrows, and only one mole of gas on the right. As the reaction moves to the right, the number of moles present would reduce, and so the pressure would reduce.

Volume: For this reaction, if the volume of the container is increased, the reaction would move to the left, where there are more moles of gas than there are on the right. Increases of volume and decreases of pressure are complementary processes. They can be effected by a piston-cylinder reaction vessel.

Temperature: The reaction is exothermic. It gives off heat. If the temperature on the system were increased, the reaction would move to the left, thereby absorbing some of the heat added.

To easily apply Le Châtelier’s principle, think of the arrows as a funnel for the reaction. The material on the left side can flow to the right, and the right side can flow to the left. If you “push” or “pull” on one side of the reaction by changing the concentration of a reactant, the quantities will “flow” through this funnel in a way to offset the change. If you increase the pressure (or decrease the volume) for the system, the reaction will flow in a direction to offset the increase, if possible. If you change the temperature, the system will flow in the direction that offsets the temperature change.

EXPERIMENT

Supplies

You will use test tubes from your drawer. You will estimate quantities of reactants, adding solutions from transfer pipets attached to the reagent bottles. These are marked to the proper volume. You will add other reactants by drop.

Except for Part 6, all of the reactions shown take place in water. The (aq) appendage, which shows that a substance is in water, is left off so that the equations would fit in the space allowed.


\[ 2\text{CrO}_4^{2-} + 2\text{H}_3\text{O}^+ \rightleftharpoons \text{Cr}_2\text{O}_7^{2-} + 3\text{H}_2\text{O} \]

yellow orange

Place about 1 milliliter of 1 M \( \text{K}_2\text{CrO}_4 \) in a test tube. Add several drops of 3 M \( \text{H}_2\text{SO}_4 \). Stir. Now add drops of 6 M \( \text{NaOH} \) with stirring until a change takes place. Add more \( \text{H}_2\text{SO}_4 \). Record your observations and explain what happened using Le Châtelier’s principle. You need to know that \( \text{H}_2\text{SO}_4 \) produces \( \text{H}_3\text{O}^+ \) ions in solution, and \( \text{NaOH} \) produces \( \text{OH}^- \) ions which remove \( \text{H}_3\text{O}^+ \) ions.

Dispose of the solution in the waste container marked “Chromate Waste”.

Part 2: Indicator Equilibria.

There is a class of dyes that changes color depending on the concentration of \( \text{H}_3\text{O}^+ \) ions in solution. These dyes are called acid-base indicators. The generic reaction

\[ \text{HIn} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{In}^- \]

one color another color

shows how the indicators work. They are usually carbon containing compounds with benzene rings. The concentration of \( \text{H}_3\text{O}^+ \) required to shift the equilibrium differs for different indicators. Methyl orange is red in the \( \text{HIn} \) state, yellow-orange in the \( \text{In}^- \) state. If the \( \text{H}_3\text{O}^+ \) is greater than \( 10^{-4} \) (pH of 4), methyl orange shifts to the \( \text{HIn} \) state. Phenolphthalein is colorless in the \( \text{HIn} \) state, pink in the \( \text{In}^- \) state. If the \( \text{H}_3\text{O}^+ \) is greater than \( 10^{-9} \) (pH of 9), phenolphthalein shifts to the \( \text{HIn} \) state.

Place about 1 milliliter of deionized water into each of two test tubes. Add a drop of methyl orange to one, a drop of

Fe$^{3+}$ + SCN$^-$ ⇌ Fe(SCN)$_2^+$

pale yellow deep red

Pour about 1 milliliter of deionized water to each of three test tubes. Add 1 drop of 0.1 M Fe(NO$_3$)$_3$ and 1 drop of 0.1 M KSCN to each test tube. Add two more drops of 0.1 M Fe(NO$_3$)$_3$ to one of the tubes, and two more drops of 0.1 M KSCN to another of the test tubes. Try to compare the colors of the solutions as quantitatively as possible. Record your observations and explain what happened using Le Châtelier’s principle.

Dispose of the solutions in the sink.

Part 6: Temperature Effect.

CoCl$_4^{2-}$ + 6 H$_2$O ⇌ Co(H$_2$O)$_6^{2+}$ + 4 Cl$^-$ + energy

purple pink

Pour about 2 milliliters of 0.15 M CoCl$_2$ (in methanol) into a test tube. Add deionized water drop by drop with stirring until the blue color just changes to pink. Do not add excessive water. Place the test tube in a water bath in the fume hood. The temperature in the water bath should be 65 to 70 °C. When the color changes, remove the test tube from the hot water bath, and cool it by swirling it in tap water. (If you do not see a color change, you may have added too much water. Remake the solution. Take care to follow directions.) Record your observations and explain what happened using Le Châtelier’s principle.

Dispose of the solution in the waste container marked “Cobalt Waste”.

Part 7: Saturated Equilibrium.

NaCl(s) ⇌ Na$^+$(aq) + Cl$^-$(aq)

Pour about 1 milliliter of saturated NaCl solution into a test tube. Add 12 M HCl drop by drop with stirring until you see a change taking place in the test tube. Continue to add 3 or 4 more drops, pausing after each drop. Record your observations and explain what happened using Le Châtelier’s principle.

Dispose of the solution in the sink.
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QUESTIONS

1. What you did in Parts 3, 4, 5, and 7 are examples of the common ion effect. Why do you suppose it has that name? Give an explanation of the common ion effect based on what you did and what you observed.

2. Rewrite the chemical equation from Part 6 using \( \Delta H \) notation for energy. Simply indicate if the \( \Delta H \) is + or -. 

3. Write the following equation in the manner the equation in Part 6 is written (note the energy term):
   
   \[
   2 \text{H}_2\text{O}(l) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}_2(aq) \quad \Delta H = 196.1 \text{kJ}
   \]

4. In Part 7, the \([\text{Cl}^-]\) in saturated NaCl is 5.4 M at room temperature. Assume that you had 1.00 ml of the saturated solution, and that you added 0.50 ml of 12 M HCl. What is the \([\text{Cl}^-]\) after you added the HCl? (When two solutions contain the same component, the numerator consists of the sum of the volume times the concentration for each solution. The denominator is the total volume.

5. Ammonia, \(\text{NH}_3\), has a distinctive smell. In Part 4, how do you think the smell of the solution would be affected by the addition of NaOH? Explain.

6. Write out the \( K_{eq} \) expression for each reaction shown in the seven parts of the experiment. For reactions in water solutions, \([\text{H}_2\text{O}]\) is not shown in the expression because it is usually a large and relatively constant value.