INVESTIGATING CHEMICAL EQUILIBRIUM

INTRODUCTUON

This lab investigation is concerned with observing the effect on various equilibria when a reactant or product is added or removed or the temperature is changed. **The following theoretical points must be understood in order for you to analyze the observations you make.**

Assume you have the equilibrium reaction $A \rightleftharpoons B$.

(a) Molecules of A and B both exist at the same time in the reaction vessel. The only thing that changes in an equilibrium is the relative amounts of A and B. The stress produces a shift in concentration that may be recognized by changes in macroscopic properties of the system.

(b) Since the rate at which a chemical reacts increases when the concentration of the chemical increases, the following statements are true.

- If the concentration of a **REACTANT** increases, the rate of the **forward** reaction also **increases** and the amount of **products** being formed **increases.** The reaction can therefore be thought of as **SHIFTING TO THE PRODUCT SIDE;** that is, a "wave" of reactants changes to products.

$$A \rightleftharpoons B$$

- If the concentration of a **PRODUCT** increases, the rate of the **reverse** reaction **increases** and the amount of **reactants** being formed **increases.** The reaction can therefore be thought of as **SHIFTING TO THE REACTANT SIDE;** that is, a "wave" of products changes to reactants.

$$A \rightleftharpoons B$$

HAZARD WARNINGS

- NaOH solutions are VERY corrosive. Wash any NaOH off your skin
- HCl solutions are corrosive and inhaling the fumes from concentrated HCl may damage your lungs. If you get any HCl solution on your skin, wash the affected area
- The following are poisonous – take care not to ingest any or get them into open wounds: $CoCl_2 \cdot 6H_2O$, and $CuSO_4$.

PROCEDURE

IMPORTANT: Any time two solutions are mixed together you must stir them. If one solution is added a bit at a time to another solution, stirring/mixing must occur after each addition.

Part I: Equilibrium Involving Bromothymol Blue Indicator

The object of this part of the investigation is to answer the question: What happens to the indicator dye bromthymol blue when solutions of the dye are made acidic or basic?

OBSERVATIONS TABLE I: The reactions of Bromthymol blue

Initial colour of Bromothymol Blue in water:			
Reagant added	Stress	Colour change and # of drops required	Direction of equilibrium shift
Add 0.1 M HCL solution (step 2)			
Add more 0.1 M HCl solution (step 3)			
Add 0.1 M NaOH solution (step 4)			
Add more 0.1 M NaOH solution (step 5			

1. Obtain 2 clean, empty, dry 250 ml Erlenmeyer flasks and add 100ml of distilled water and 1 ml (10 drops) of bromothymol blue solution to each flask. Record the colour of the solution in Table 1.
2. To the first flask add a single drop of 0.1M HCl. Swirl the flask and continue to add drop by driop (count them!) until a definite colour change is observed. The second flask a control- don't add anything to it. Compare the solution colours. Record the new colour and the number of drops required for this change in Table 1. Record your observations.
3. Continue adding 0.1M HCl drop wise to the first flask until a second colour shift occurs. Compare with the control and record the new colour change and number of drops required for this change in Table 1
4. Now add 0.1M NaOH drop wise into the first flask until a definite colour change is observed. Record the colour change and the number of drops required in Table 1.
5. Continue the drop wise addition of 0.1M NaOH until the colour changes again. Record the colour change and the number of drops required in Table 1. Dispose of the used chemicals down the sink.

Part II: Equilibrium Involving Thiocyanatoiron (III) Ion

The object of this part of the investigation is to answer the question**:** What effect does changing the concentration of various ions have on an equilibrium reaction involving the thiocyanatoiron ion?

OBSERVATIONS TABLE 2: The reactions of Thiocyanatoiron (III) Ion

Initial colour of $FeCl_3$: Initial colour of KSCN: Colour of $FeCl_3$ and KSCN mixed together (step 2):			
Reagent added	Stress	Observations	Direction of Equilibrium shift
Addition of KCl (step 5)			
Addition of $Fe(NO_3)_3$ (step 6)			
Addition of KSCN (step 7)			
Addition of NaOH (step 8)			

1. Place 1 ml of 0.2 M $FeCl_3$ into a 250 ml beaker. Using a graduated cylinder, measure out 1 ml of 0.2 M KSCN. Record the coour of each solution in Table 2.
2. Add the 1ml KSCN solution to the beaker containing the 0.2M $FeCl_3$. Swirl the mixture and record the colour in Table 2. Add enough distilled water to the solution to dilute the intense colour to a light amber colour (approximately 80 ml).
3. Pour 5 ml of this solution into each of 5 test tubes labelled A to E. Test tube A serves as a control.
4. For each of the following reactions (steps 5 – 8), record the results in Table 2. To record the 'stress' involved, state which ion in the original equilibrium changed concentrations, and whether the change was an increase or decrease.
5. To test tube B, add 10 drops of 0.2M KCl.
6. To test tube C, add 10 drops of 0.2M Fe $(NO_3)_3$
7. To test tube D, add 10 drops of 0.2M KSCN
8. To test tube E, add 10 drops of 6.0M NaOH

Part III: The Effect of Temperature on an Equilibrium Involving Cobalt Complexes

The object of this part of the investigation is to answer the question**:** What effect does changing the temperature have on an equilibrium reaction?

OBSERVATIONS TABLE 3: The effect of changing the temperature in an equilibrium involving cobalt complexes

Procedure	Stress	Observations	Direction of Equilibrium Shift
Addition of 6M HCl to first beaker (step 1)			
Addition of water to second beaker (step 2)			
Addition of water to first beaker (step 4)			
Heating the first beaker.(step 5)			
Cooling the first beaker (step 6)			

1. Weigh out 0.3 g of $CoCl_2 \bullet 6H_2O$ (about 1/3 of a level spoonful) into each of two 100ml beakers.
2. To the first beaker, add 10 ml of 6M HCl. Record the colour in Table 3.
3. To the second beaker, add 10 ml of water. Record the colour in Table 3.
4. Gradually add water to the first beaker until a definite colour change occurs. Record your observations in Table 3. Dispose of the used chemicals down the sink**.**
5. Place the first beaker on a hot plate and adjust the heat to gently warm (approximately number 4 on the hot plate). When a definite colour change is observed, turn off the hot plate. Using beaker tongs, remove the beaker from the hot plate. Record the resulting colour in Table 3.
6. Add about 50 ml of cold tap water to a clean 250 ml beaker. Carefully place the warm beaker and contents from Step 4 into this cold water bath. Record any additional colour changes in Table 3.

Part IV: The Effect of Concentration Changes on Copper Complexes Equilibrium

The object of this part of the investigation is to answer the question**:** What effect does changing the concentration have on an equilibrium reaction?

OBSERVATIONS TABLE 4: The effect of changing ion concentrations in an ionic equilibrium

Procedure	**Observations**
Addition of NH_4 to $CuSO_4$ (step 2)	
Adding more NH_4 (step 3)	
Addition of HCl (step 4)	

1. Place 2 ml of 0.1M $CuSO_4$ in a test tube. Record the colour**.**
2. Add 3 drops of 1M NH_4 and observe the result.
3. Continue adding 1M NH_4 until another change occurs
4. Add 1M HCl drop wise until a change occurs. Record your observations in Table 5. Dispose of the used chemicals down the sink**.**

QUESTIONS

Part I: Equilibrium Involving Bromthymol Blue Indicator

The two relevant equilibrium equations for this investigation are:

$$Brom^- + H^+ \rightleftharpoons HBrom \quad ... (1)$$
$$HBrom + OH^- \rightleftharpoons Brom^- + H_2O \quad ... (2)$$

You should know that when HCl and NaOH dissolve in water, they completely ionize as shown below

$$\mathbf{H}Cl(aq) \longrightarrow \mathbf{H^+}(aq) + Cl^-(aq) \quad \text{and} \quad Na\mathbf{OH}(aq) \longrightarrow Na^+(aq) + \mathbf{OH^-}(aq)$$

and that the $Na^+(aq)$ and $Cl^-(aq)$ are called "spectator ions" and can be ignored in this part of the investigation.

1. Bromthymol blue solutions always contain some molecules of both **HBrom** (the acidic form of bromthymol blue indicator dye) and **Brom⁻** (the basic form of bromthymol blue indicator dye).
   (a) ***Theoretical argument***: According to equations 1 and 2 (above box), does the bromthymol blue equilibrium produce more HBrom or $Brom^-$ when: i) NaOH is added? ii) HCl is added?
   (b) ***Experimental argument***: What colour is $Brom^-$? What colour is HBrom?

2. An "acidic" solution has an excess of $H^+(aq)$ present, a "basic" solution has an excess of $OH^-(aq)$ present and a "neutral" solution (pH = 7) has equal amounts of H^+ and OH^- present. According to the results of your investigation, how can bromthymol blue be used to help decide the exact point at which the dropwise addition of a basic solution to an acidic solution creates a neutral solution?

Part II:

Part III: The Effect of Temperature on an Equilibrium Involving Cobalt Complexes

The relevant equilibrium equation for this investigation is:

$$Co(H_2O)_4Cl_2 + 2\ H_2O \rightleftharpoons Co(H_2O)_6^{2+} + 2\ Cl^- \quad ... (5)$$

8. All the solutions used in this investigation had at least some molecules of both $Co(H_2O)_6^{2+}$ and $Co(H_2O)_4Cl_2$ present at all times.
   (a) ***Theoretical argument***: In procedure step 14 an excess of H_2O is added. Which way does equilibrium equation (5) shift in step 14?
   (b) ***Experimental argument***: Based on your observations from steps 13 and 14, what colour is:
   i) $Co(H_2O)_6^{2+}$? ii) $Co(H_2O)_4Cl_2$?

9. Which way does equilibrium equation (5) shift when
   (a) the solution is heated? (b) the solution is cooled?

10. Based on your answer to question 9, is "heat" on the reactant side or product side of equilibrium equation (5)? Explain your reasoning. Is the reaction EXOTHERMIC or ENDOTHERMIC as written?

Part IV: The Effect of Concentration Changes on Copper Complexes Equilibrium

The relevant equilibrium equation for this investigation is:

$$CuSO_4(aq) + 4\ Br^- \rightleftharpoons CuBr_4^{2-}\ (aq) + SO_4^{2-} \quad \text{... (4)}$$

6. (a) ***Theoretical argument:*** In procedure step 11 an excess of Br^- is added (in the form of NH_4Br, which ionizes in water and acts as a source of Br^-), while in step 12 an excess of SO_4^{2-} is added (in the form of $(NH_4)_2SO_4$, which ionizes in water and acts as a source of SO_4^{2-}). Which way does equilibrium equation (4) shift in step 11? Which way does the equation shift in step 12?

   (b) ***Experimental argument:*** Based on your observations from steps 10, 11 and 12, what colour is:
   i) $CuSO_4(aq)$ ii) $CuBr_4^{2-}$ (aq)

7. Explain how your theoretical arguments explain your experimental observations.