Reversible and Irreversible Processes

Investigation Questions

- What is equilibrium?
- What does the Le-Chatelier's principle state?
- How can you tell if equilibrium is reached in a reaction?

Introduction

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Physical and chemical processes can be considered as either reversible or irreversible processes. A common reversible physical process is the melting of ice to form water and the freezing of water to form ice at 0 ˚C. However, not all physical processes are reversible. Consider the use of a wood chipper to mulch a small tree. You will physically change the tree, but the mulching process is not reversible because you could not run the mulch "backwards" through the chipper to reproduce the tree. This process of "mulch → tree" using a wood chipper is irreversible.

Chemical reactions are often associated with being irreversible, and a common example is the combustion of gasoline in the presence of air. Hydrocarbon fuels react with oxygen to form carbon dioxide and water as products, and the process is considered irreversible. However, chemical reactions are often reversible. For example, eyeglasses that can darken when exposed to light are able to do so because of a reversible chemical reaction. Tiny crystals of silver chloride are finely dispersed throughout the glass of the lens, and these dispersed crystals appear invisible to the eye (similar to how sugar appears invisible when dispersed in water). When exposed to light, the silver chloride crystals dissociate into silver atoms and chlorine atoms. These metal atoms of silver appear gray and darken the lens. The reverse reaction of silver and chlorine atoms combining to form silver chloride starts to take place immediately, but the lens only becomes clear again in the absence of light, which allows the silver chloride crystals to retain their original form and properties.

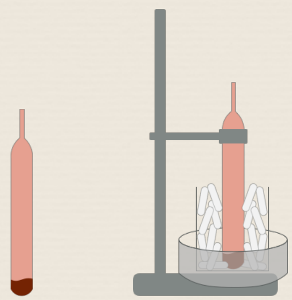
Equilibrium is the condition in which two opposing processes are occurring simultaneously and at the same rate. In the example of the photosensitive eyeglasses, an equilibrium condition exists when the amount of light that is present is constant. The opposing processes of silver chloride dissociation and silver chloride reformation occur simultaneously and at equal rates, and this is written as follows:

$$AgCl \rightleftharpoons Ag^{+} + Cl^{-}$$

In this experiment, you will investigate several reversible processes as an introduction to the equilibrium condition as applied to chemistry.

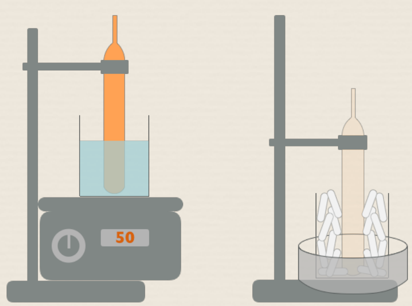
Part 1. The physical equilibrium between bromine vapor and bromine liquid (for 20 min)

Your TA will demonstrate the equilibrium between bromine in the gas phase and bromine in the liquid phase. Record your observations for each step in the demonstration.



Part 2. The gas-phase chemical equilibrium between NO2 and N_2O_4 (for 20 min)

Your TA will demonstrate the equilibrium between NO_2 and N_2O_4. Record your observations for each step in the demonstration.



Analysis Questions Parts 1 and 2

Show balanced chemical equations for full credit.

Part 3. Equilibrium of aqueous cobalt chloride (for 90 min)

Introduction

An aqueous solution of cobalt chloride appears pink at low concentrations of chloride and blue at high concentrations of chloride. The pink color results from the presence of $[Co(H_2O)_6]^{2+}$ ions, usually called "hexa-aqua complex of Co^{2+}", and the blue color results from the presence of $[CoCl_4]^{2-}$ ions, usually called "tetrachloride complex of Co^{2+}". In this study, you will investigate the effect of changing the chloride concentration and the effect of changing the temperature on the equilibrium between $[Co(H_2O)_6]^{2+}$ ions and $[CoCl_4]^{2-}$ ions.

Equipment

- Beakers
- Hot plate
- 13x100 mm test tubes

Chemicals and Safety Information

WEAR GLOVES, SAFETY GLASSES AND LAB COAT WHEN WORKING IN LAB. USE UNDER HOOD*.

Compound	Hazards
water $H_2O_{(l)}$	No significant hazards
hexa-aquacobalt* $Co(H_2O)_6^{2+}{}_{(aq)}$	Eye and skin irritant

tetrachlorocobalt in 2-propanol solution* $Co(Cl)_4^{2-}$ *(aq)*	Eye and skin irritant
2-propanol* $(CH_3)_2CHOH$ *(l)*	Flammable, eye and skin irritant
calcium chloride* $CaCl_2$ *(in 2-propanol)*	Eye and skin irritant

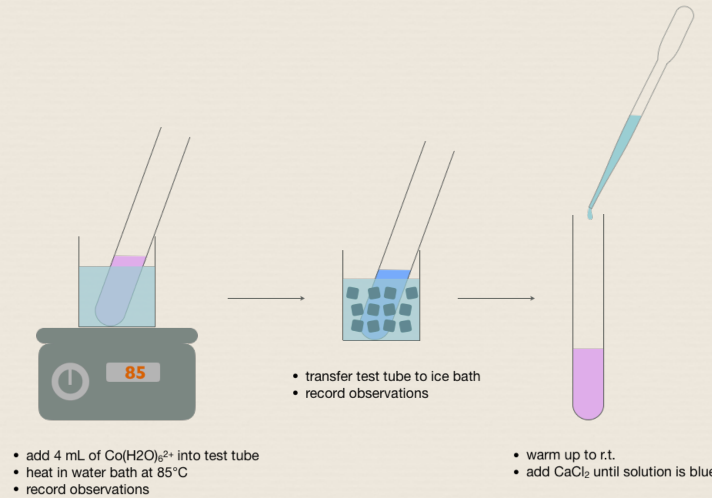
Waste Disposal

Dispose of the products by pouring them into the proper waste container.

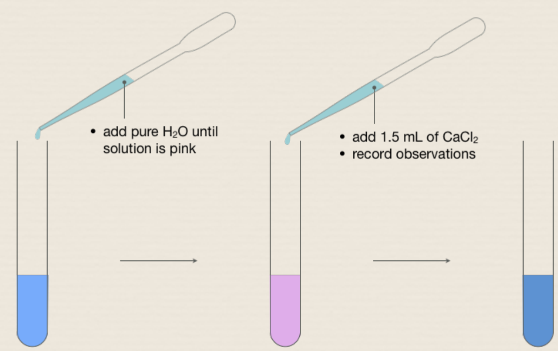
Procedure

a. Set up a hot-water bath at 85°C using a 250-mL glass beaker. Also set up an ice-water bath using a 250-mL glass beaker.

b. Obtain 4 mL of $[Co(H_2O)_6]^{2+}$ solution in a 13x100-mm test tube. Place the tube into the 85°C bath, then place the tube into an ice-water bath. Record your observations (**NOTE**: $[Co(H_2O)_6]^{2+}$ solution contains small impurities of Cl^- ions).

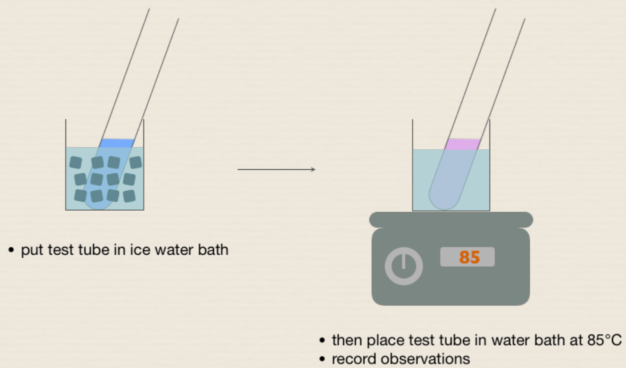


c. Let the tube reach room temperature. Add drops of the $CaCl_2$ solution until the solution appears blue in color, indicating the presence of high concentrations of $[CoCl_4]^{2-}$ ion. Add drops of distilled H_2O until the solution appears pink in color. Now add 1.5 mL of the $CaCl_2$ solution. Record your observations.

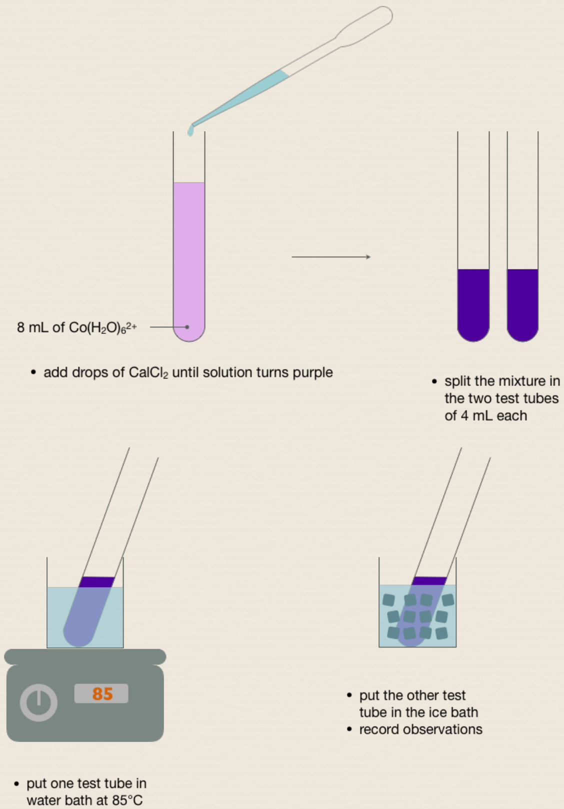


d. Obtain 4 mL of $[CoCl_4]^{2-}$ solution in a 13x100-mm test tube. Add drops of distilled H_2O until the solution contains mostly $[Co(H_2O)_6]^{2+}$ ions and appears pink in color. Now add 1.5 mL of the $CaCl_2$ solution. Record your observations.

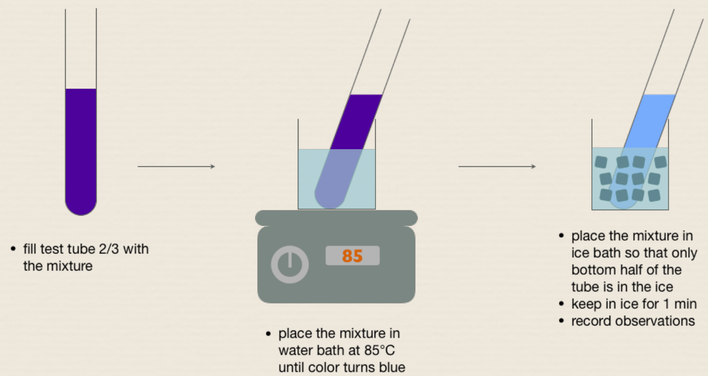
e. Put the test tube in the ice-water bath. Then, place it into the 85˚C bath. Record your observations.



f. Fill one 13x100-mm test tube with 8 mL of $[Co(H_2O)_6]^{2+}$ solution. Set up an ice-bath in your 400-mL plastic beaker. To the $[Co(H_2O)_6]^{2+}$ solution, add drops of $CaCl_2$ solution until the solution appears purple in color. Fill two 13x100-mm test tubes with 4 mL of this Mixture (purple solution) in each tube. Place one tube into the 85°C bath and the other tube into the ice-water bath. Record your observations.



g. Fill a single 13x100-mm test tube about 2/3 full of this Mixture (purple solution) by combining the test tubes used at point “f”. Place the tube into the 85°C bath until the solution appears blue in color, then immediately place only the bottom third of the tube into the ice bath for about 60 seconds (so that half the solution is in ice, and half the solution is not in ice). Occasionally remove the tube from the ice very briefly, and record your observations.



Analysis Questions Part 3

Show all balanced chemical equations for full credit.

1. Is there a reversible reaction for the aqueous solution of cobalt chloride?
2. Write the equation for the reaction of aqueous cobalt chloride. If the reaction is irreversible, use the single arrow (→) to show the direction of the reaction. If the reaction is reversible, use the double arrow ($\rightleftharpoons$) to show reversibility.
3. Is there a separate purple form of cobalt chloride? Explain.
4. Was an equilibrium condition achieved with aqueous cobalt chloride? Explain.
5. Did the temperature have an effect on any equilibrium condition or position? Explain.

Part 4. Absorbance vs. wavelength for $[CoCl_4]^{2-}$ solution, $[Co(H_2O)_6]^{2+}$ solution, and a mixture of $[Co(H_2O)_6]^{2+}$ (pink) and $[CoCl_4]^{2-}$ (blue)

Equipment

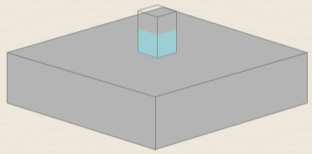
- spectrometer
- cuvettes

Waste Disposal

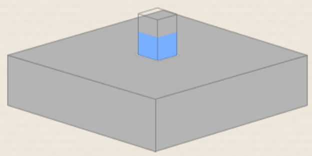
Dispose of the products by pouring them into the proper waste container.

Procedure

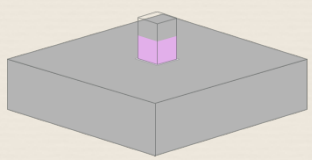
a. Prepare a <u>first cuvette</u> with distilled water.
b. Dilute your stock solution of $[CoCl_4]^{2-}$ (blue) solution in a ratio of 10 parts (10 mL) of 2-propanol solvent to 1 part (1 mL) of $[CoCl_4]^{2-}$ (blue) solution. Prepare 11 mL of this solution. You will use approximately half here and the other half to prepare the forth cuvette (point d). Prepare a <u>second cuvette</u> with the diluted $[CoCl_4]^{2-}$ (blue) solution.
c. Prepare a <u>third cuvette</u> with $[Co(H_2O)_6]^{2+}$ (pink) solution. The solution does not need to be diluted.
d. In a beaker, mix 3 mL of $[Co(H_2O)_6]^{2+}$ (pink) and 3 mL of dilute $[CoCl_4]^{2-}$ (blue) from point b. Prepare a forth cuvette with this **mixture.**
e. Set the spectrophotometer at 350 nm. Place the cuvette filled with distilled water into the sample holder. Press the 0 Absorbance/100% Transmittance calibration button.



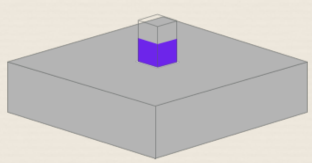
f. Remove the cuvette containing distilled water (save the cuvette and water) and replace it with the cuvette containing the $[CoCl_4]^{2-}$ solution. Record the ABSORBANCE.



g. Remove the cuvette containing the diluted $[CoCl_4]^{2-}$ solution and replace it with the cuvette containing the $[Co(H_2O)_6]^{2+}$ solution. Record the ABSORBANCE.



h. Remove the cuvette containing the $[Co(H_2O)_6]^{2+}$ solution and replace it with the cuvette containing the **mixture** solution. Record the ABSORBANCE.



i. Remove the solution and reset the spectrophotometer to 375 nm.

j. Place the cuvette filled with distilled water into the sample holder. Press the Absorbance/100% Transmittance calibration button.

k. Remove the cuvette containing distilled water (save the cuvette and water) and measure the ABSORBANCE of the three samples ($[CoCl_4]^{2-}$ solution, $[Co(H_2O)_6]^{2+}$ solution, and **mixture** solution]).

l. Continue to take absorbance readings every 25 nm until you reach 750 nm for each solution. With each new wavelength, you must re-zero the instrument with the distilled water blank and then read the absorbance for each solution. You will collect 17 data points per solution.
   i. Review your absorbance data. Look for the highest absorbance reading that you have made.
   ii. What is the wavelength at which that occurs?

m. Show your data to your TA. They will recommend a range or ranges over which you should repeat your readings every 5 nm to determine more precisely how the solution is absorbing light in the region of maximum absorbance.

n. Plot your absorbance vs. wavelength data for the $[CoCl_4]^{2-}$ solution, the $[Co(H_2O)_6]^{2+}$ solution, and the **mixture** of $[CoCl_4]^{2-}$ and $[Co(H_2O)_6]^{2+}$.

Analysis Questions Part 4

Show **tables** of **all** wavelength vs absorbance data, and graphs of wavelength vs absorbance for full credit.

1. Where do you observe the maximum absorbance for each individual solution? Where do you observe minimum absorbance for each individual solution?
2. What wavelength of light is being absorbed at the point of maximum absorbance on each graph? Record these wavelengths.
3. What color is the light being absorbed at the point of maximum absorbance on each graph?
4. Compare the plot of the mixture to the other two plots. How are they similar? How are they different?
5. Refer to the other two plots and note the wavelengths at which maximum absorbance was recorded. What do you notice at these same wavelengths on the third plot?
6. What can you conclude from your observations in this experiment?

Post Discussion Questions

Answer to all the following questions for full credit.

- What types of equilibrium did you observe?
- How were changes in equilibrium manifested?
- Were they reversible or irreversible reactions?
- How did you change the equilibrium in parts 1 and 2?
- How did you change the equilibrium in part 3?
- How does the Le-Chatelier's principle relate to the reactions you explored?
- How did you identify the different species involved in the equilibrium in part 3 and 4?

Finishing Up

Create a heading that says "Reflective Writing" and complete the reflective writing portion of your lab notebook after lab class. See the ELN rubric (below) for details about what to include.

Submit your lab report by clicking on the "Submit" button within your LabArchives at the top of your ELN using the assignment link given in the content area labeled "Week 1" on Canvas. The assignment link is labeled "ELN".

REMEMBER TO LOGOUT BEFORE YOU LEAVE.

Remember to take your **post-lab quiz** for this lab and the **pre-lab quiz** for the next lab by the appropriate deadlines (below).

Deadlines

	Deadline	Points
Pre-lab Quiz	BEFORE performing the experiment	20
Pre-lab Writing	BEFORE coming to lab class	Part of ELN Report
ELN Report	11:59 PM the third day after performing the experiment	40
Post-lab Quiz	BEFORE performing the NEXT experiment	40

ELN Rubric

Category	Requirements	Points
Basic	**What to look for: if any one of these is missing, it will be zero points.** • *Title of the experiment* • *Partner's name* • *Use of headings*	**0-1**
Pre-lab Writing	**This section MUST be completed before lab as evidenced by timestamp. Any part that is copied and pasted from the lab manual will receive zero points. Everything in this section must be rewritten in your own words.** Student must include: • *(2 pts) Restate investigation questions* • *(3 pts) Experimental procedure (use numbered list)* • *(2 pts) List of safety hazards specific to this experiment*	**0-7**
TA Points	**TA choice** *Includes lab cleanliness, respectful behavior.*	**0-4**

Procedure Changes, Raw Data Recording, Observations	**This section MUST have lab period timestamp.** • *Any changes from the procedure described in the procedure list are noted (please refer to the number in the list for easy referral). Please list ONLY changes to the general procedure.* • *Raw Data and Observations: any tables, observations, measurements, etc. indicated in the lab reading must be included in this section.*	**0-6**
Analysis & Data Manipulation	**This section might be completed outside the lab period.** *Answers to ALL analysis questions are given. Any required calculations are given and work is shown.*	**0-10**

Reflective Writing	**This section might be completed outside the lab period.**
	• *(7 pts)* ***Explain:*** *ALL Post Discussion Questions are answered and justified using data and observations.*
	• *(2 pts)* ***Evaluate:*** *Discussion of whether answers to Investigation Questions and Post Discussion questions make sense based on what students have learned in lecture. Specifically:*
	  ‣ *Are your conclusions consistent with what is expected?*
	  ‣ *Are your results consistent with your entire class? If not, why not?*
	  ‣ *What would you do differently in order to get even better results? Saying anything that has to do with "human error" will not receive any credit.*
	• *(3 pts)* ***Extend:*** *Discussion of how what was learned in lab ties in with anything related to your major (or other scientific field if this does not apply to your major). Two specific examples must be shown (this might require some independent literature search).*
		0-12