7. The Absorption Spectrum of Cobalt(II) Chloride

Introduction

When hydrogen and other gaseous substances are heated, they will *emit* light with a few characteristic frequencies (Ebbing/Gammon, Section 7.3). In contrast, matter will also *absorb* discrete frequencies of light. This process is exactly the opposite of emission.

During the absorption of light, an electron undergoes a transition from a lower-energy (usually the lowest-energy) level to a higher-energy level. The electron gains energy in this process by absorbing a photon, whose energy (E) is given by Einstein's equation, $E = hv$. The energy of the photon corresponds to the difference in energy between the higher-energy and lower-energy levels. As a result of the transition, a component of light with a frequency v is absorbed, and other frequencies are transmitted.

Some further aspects of the absorption of light by solutions of colored substances are discussed in Appendix C. The amount of light absorbed by a substance in solution is dictated by the concentration of that substance; absorption decreases as the concentration is decreased by dilution. This statement is expressed mathematically in Beer's law (see Appendix C). You must understand the calculation of the concentration of a solution after dilution (Ebbing/Gammon, Section 4.8) before you can use or appreciate this law.

Purpose

You will investigate the absorption of light by a series of solutions of cobalt(II) chloride ($CoCl_2$). You will also receive a solution of this substance whose concentration is unknown but too large for an accurate measurement of the absorption of light. Your task will be to determine the concentration of this solution.

Concept of the Experiment

The absorbance of a 0.150 M solution of $CoCl_2$ will be measured before and after a series of dilutions. For each dilution you will calculate the new concentration of $CoCl_2$. According to Beer's law, the slope of the best straight line from a graph in which absorbance is plotted against the concentration of $CoCl_2$ will give you k (the constant from Beer's law) for $CoCl_2$ under your experimental conditions. You will obtain the slope by a method called linear regression. This method is discussed in Appendix C. You may do this calculation by hand, or, if your laboratory instructor wishes, you may use a computer and the Internet.

You will also receive a solution of $CoCl_2$ whose concentration is unknown but so large that the absorbance is too great to be reliably measured. You must determine the concentration of $CoCl_2$ in this solution from a measurement of a diluted solution. It will be up to you to discover an appropriate dilution.

Before you measure any of these absorbances, however, you will need to find the correct wavelength for the measurements. This wavelength, which will be the wavelength in the absorption spectrum of $CoCl_2$ at which the maximum absorbance occurs, will allow maximum sensitivity for each measurement.

Procedure

Getting Started

1. Your laboratory instructor may ask that you work in groups rather than alone.
2. Obtain directions for discarding the solutions that you will use in this experiment.
3. Obtain instructions for using your spectrophotometer.
4. Obtain your unknown.

Making the Measurements

1. Mark each of 7 dry 18 × 150-mm test tubes with one of a series of identification numbers running from 1 to 7.
2. Use Mohr pipets to make the additions of 0.150 *M* $CoCl_2$ and distilled water shown in the table below.

CAUTION: Never use your mouth to draw liquid into a pipet, even if the liquid is water. Use a rubber suction bulb or some other suction device.

Test Tube No.	0.150 *M* $CoCl_2$ Solution (mL)	Distilled Water (mL)
1	5.0	0
2	4.0	1.0
3	3.5	1.5
4	3.0	2.0
5	2.5	2.5
6	2.0	3.0
7	1.0	4.0

3. Thoroughly mix the contents of each test tube. Do not use one of your fingers as a stopper.
4. Obtain the absorption spectrum of aqueous $CoCl_2$ by using the contents of the first test tube and measuring the absorbance at intervals of 25 nm between 400 and 600 nm. Do not dispose of this solution. Record your results.
5. From these measurements, select the wavelength at which the absorbance is largest. This wavelength will provide maximum sensitivity. Use this wavelength for all subsequent measurements.
6. Remeasure the absorbance of the contents of the first test tube at this wavelength. Measure the absorbances of the contents of the remaining test tubes. Record your results.
7. Label a piece of the available graph paper so that absorbance (A) appears on the vertical axis and the concentration (c) of $CoCl_2$, in mol/L, appears on the horizontal axis. Use Figure C.2 in Appendix C as an exact model.

8. Enter each point on the graph as a small, blackened circle. Do the data appear to conform to a straight line? Use linear regression (Appendix C), either by hand or by using the tool available online at the student website, to calculate the slope of the best straight line that satisfies these points. Linear regression materials can be found at

   http://college.hmco.com/PIC/ebbing9e

   If you wish, draw a straight line with this slope on your graph. This line should pass through the origin ($A = 0$, $c = 0$).

9. Now you can begin to work on your unknown. Use the following guidelines in establishing the molar concentration of $CoCl_2$ in this solution.

   a. A portion of this solution must be diluted until the absorbance lies within the range of absorbances that you found in Step 6.

   b. To establish the correct dilution, measure the absorbance after each of a series of successive dilutions. Your final result here may have a large experimental error, because errors will accrue during several dilutions.

   c. To eliminate the accumulation of experimental errors, prepare a new sample and obtain the desired absorbance in one dilution rather than a series of dilutions. Clearly, this dilution must be equivalent to the overall dilution obtained in the previous set of trials.

10. Calculate the concentration of $CoCl_2$ in the diluted solution, using the absorbance and k. Calculate the concentration of $CoCl_2$ in the original unknown.

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Instructor:	____________		____________

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Prelaboratory Assignment

1. a. What is Beer's law?

   b. According to this law, what will be the value of the slope if absorbance is plotted against concentration?

2. The following data were collected when the absorbances of a series of solutions containing $NiCl_2$ were measured:

Test Tube No.	1	2	3	4
Volume of 0.390 *M* $NiCl_2$ solution (mL)	4.0	3.0	2.0	1.0
Volume of H_2O (mL)	0	1.0	2.0	3.0
Concentration of $NiCl_2$ (*M*)	______	______	______	______
Absorbance (*A*)	0.858	0.644	0.429	0.215

   a. Complete the table by calculating the concentration of $NiCl_2$ in each solution. Show your calculations below.

b. *Prepare a graph in which the absorbances given in the table are plotted against the* concentration of $NiCl_2$ that you have just calculated. Follow Steps 7 and 8 under Making the Measurements. Use the space below to calculate k by hand using linear regression. Repeat the calculation using the tool available online at the student website if your laboratory instructor wishes.

c. The absorbance of a solution of $NiCl_2$ of unknown concentration is found to be 0.388. What is the concentration of this solution?

3. What safety rule must be observed during this experiment?

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Results

1. *The absorption spectrum of aqueous $CoCl_2$*

Wavelength (nm)	*A*	Wavelength (nm)	*A*	Wavelength (nm)	*A*
400	______	475	______	550	______
425	______	500	______	575	______
450	______	525	______	600	______

The maximum absorbance occurs at __________ nm.

2. *The absorbance as a function of the concentration (c)*

Wavelength to be used for measurements: _________ nm

Test Tube No.	*A*	*c*
1	_________	_________
2	_________	_________
3	_________	_________
4	_________	_________
5	_________	_________
6	_________	_________
7	_________	_________

Calculations of *c*:

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3. *Calculations for the slope* (Include your graph.)

k = ____________________ (Give units.)

4. *Identifying the unknown concentration*

Unknown no.: _______________

a. Trial solutions

mL of Unknown	mL of H_2O	*A*
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________

b. Final determination

Volume of unknown (mL): ____________

Volume of H_2O (mL): ____________

A = ____________

c = ____________ M

Undiluted solution: c = ____________ M

Calculations:

Question

1. a. How would you prepare 250 mL of a 0.150 M solution of $CoCl_2$ from solid $CoCl_2$ and distilled water?

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b. Using the solution from part a and distilled water, how would you prepare 100 mL of a 0.0600 *M* solution of $CoCl_2$?

c. What absorbance would you expect from the solution from part b at the wavelength of maximum sensitivity?