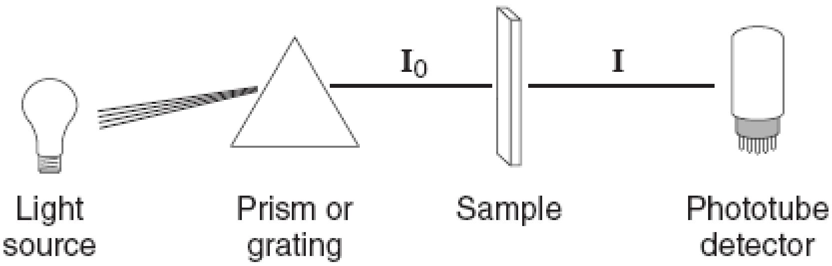
#8 Beer's Law, Cobalt Chloride

Purpose: Using Beer's Law you will find the concentration of cobalt chloride from the amount of light absorbed by its solution.

Introduction:
A spectrum is a recording of the wavelengths absorbed by a sample. Colored compounds, such as the pink cobalt chloride used in this experiment absorb in the visible.



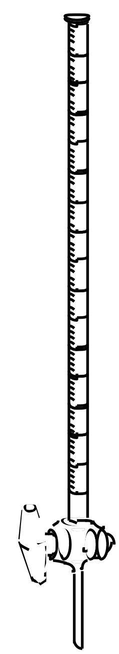
The transmittance, %T, is the ratio of the intensity of the incident light ($\mathbf{I}_0$) and the intensity of the emerging light (**I**), or %T = $\mathbf{I} / \mathbf{I}_0$. Absorbance, A, is the logarithm of 100 divided by %T :

$$A = \log \frac{100}{\%T}$$

If %T = 50, then, A = log 100/50 = log 2 = 0.30

$$0.30 = \log \frac{100}{50}$$

Find 50% T on the meter scale and notice that it corresponds to 0.30 on the Absorbance scale. The % T scale is linear and increases from left to right. The A scale is logarithmic and increases from right to left. It is more accurate to read % transmittance rather than absorbance, so record %T values and convert to A.



Beer's Law
According to Beer's Law, the absorbance (A) of a solution is proportional both to the molarity of the solute responsible for the color and to the path length (b) of solution through which the light passes.

$$A = \varepsilon \times b \times \text{molarity}$$

where ε is a coefficient (Beer's Law constant), the value of which depends on the wavelength of light, the solvent and the kind of solute used. The path length (b) is the diameter of the test tube (1-cm) used to hold the sample. Deviations from Beer's Law may be severe for concentrations greater than 0.1 M.

Apparatus
You will be taking a spectrum of cobalt chloride solution using a Spectronic-20. To use this instrument refer to the operating instructions attached. Be sure to adjust the %T dial for a 100% indication using a blank cuvette for each wavelength.

Procedure

Part A: Taking the Spectrum of the Stock Solution of Cobalt Chloride

1. The stock solution is the most concentrated solution to be used in this experiment. Pour about 50 mL of 0.080 M $CoCl_2.6H_2O$ into a clean 150 mL beaker. Fill a clean burette with the contents of the beaker.

Note: You will use the stock solution to take a spectrum and to prepare dilutions for other parts of the experiment.

2. Fill one cuvette to a level of approximately 2 cm with water (the blank) and another with the stock solution of cobalt chloride (the sample). Set the wavelength dial to 400 nm and measure the % transmittance of your sample. Record in the **Data and Results** table. Continue to measure the % transmittance every 10 nm between 400 nm and 650 nm, remembering to adjust for a full scale indication when using the blank at each new wavelength.

Note: The tubes should be clean, their outer surfaces dry and free from smudges.

3. Convert % transmittance to absorbance for each value. Plot the absorbance (y axis) vs. wavelength (x axis) by drawing a smooth line through the points (drawn to reflect experimental error). This is the visible spectrum of the stock solution of cobalt chloride. Submit the plot with your **Data and Results**. Record the wavelength at which the maximum absorbance is observed.

Part B: Measuring Absorbance of Diluted Solutions of Cobalt Chloride

1. To verify Beer's Law you will prepare dilutions of a stock solution to measure their absorbances at the maximum wavelength of the spectrum curve found in Part A.

a. Use two burettes (one for cobalt chloride, another for water).
b. Fill the $CoCl_2$ burette to the 40 ml mark with the stock solution.
c. Fill the water burette to the 50 ml mark with distilled water.
d. Deliver 10.0 mL of the stock solution into a clean 50 mL beaker, then add 5.0 mL of water to dilute the solution. Mix well.
e. Repeat step d for the following amounts:
   10.0 mL stock + 10.0 mL water
   10.0 mL stock + 15.0 mL water
   10.0 mL stock + 20.0 mL water

Calculate the concentrations (molarities) of these diluted solutions and record them .
To find a new concentration, M_2, where M = molarity and V = volume:

$$M_1 \times V_1 = M_2 \times V_2$$

Solve for M_2: $$M_2 = \frac{M_1 \times V_1}{V_2}$$

For example, when 5 mL water is added: $$M_2 = \frac{0.08M \times 10mL}{15mL} = 0.053M$$

2. Measure the % transmittance of each diluted solution at the peak wavelength observed in Part A. *Note:* Rinse the cuvette with each new solution before reading its % transmittance
.

3. Convert % transmittance to absorbance. Plot the absorbance (x axis) vs. the concentration (y axis). Be sure to make the points in your plot reflect the experimental error. The plot should produce a straight line. Submit the plot with your **Data and Results**.
Remember that the point 0,0 is also a data point.

4. To find ε, the Beer's Law constant, use the equation $m=(y_2-y_1)/(x_2-x_1)$, where y_1 and y_2 are two different concentrations and x_1 and x_2 are the corresponding absorbance points.

Part C: Determining the Concentration of an Unknown Cobalt Chloride Solution

1. Record the code number/letter of your unknown. Measure the % transmittance of the sample at the peak wavelength used for the known samples, convert to A and use the value of ε calculated in Part B to find the concentration of your unknown sample using the equation: molarity = A / (ε x b)

Data and Results (Beer's Law $CoCl_2$)

Name(s) ____

Part A: Taking the Spectrum of the Stock Solution of Cobalt Chloride

Concentration of $CoCl_2$ stock solution (see label) ____________ M

λ nm	%T	A	λ nm	%T	A
400			560		
410			570		
420			580		
430			590		
440			600		
450			610		
460			620		
470			630		
480			640		
490			650		
500			660		
510			670		
520			680		
530			690		
540			700		
550					

Wavelength where absorbance is maximum (Peak Wavelength): _________ nm

Absorbance at Peak Wavelength: _________

Data and Results 2 (Beer's Law $CoCl_2$)

Part B: Measuring Absorbance of Diluted Solutions of Cobalt Chloride

H_2O added mL	Molarity	%Transmittance	Absorbance
0			
5			
10			
15			
20			

Path length: __________ cm

Beer's Law Coefficient ε : __________ $M^{-1}cm^{-1}$

(Attach absorbance vs. concentration plot)

Part C: Determining the Concentration of an Unknown

Code number/letter of the Unknown: __________

Absorbance of the Unknown at the Peak Wavelength: ____________

Concentration of the Unknown: ____________ M

Questions:

1. Would you be able to use your data to find the concentration of a 1.00 M solution of Cobalt chloride? Why or why not?

2. Describe two different ways that could be used to prepare 100 mL of a 0.0400 M solution starting from a stock (100%) solution of 0.080 M $CoCl_2$ $6H_2O$ (237.93 g/mol).

Instructor's Guide
(#8 Beer's Law $CoCl_2$)

Part A: Taking the Spectrum of the Stock Solution of Cobalt Chloride

Concentration of $CoCl_2$ stock solution (see label) *0.080* M

λ (nm)	%T	A	λ (nm)	%T	A
400	*98*	*0.01*	530	*44*	*0.36*
410	*89*	*0.05*	540	*52*	*0.28*
420	*85*	*0.07*	550	*60*	*0.22*
430	*80*	*0.09*	560	*70*	*0.16*
440	*71*	*0.15*	570	*77*	*0.11*
450	*63*	*0.20*	580	*84*	*0.08*
460	*54*	*0.26*	590	*87*	*0.06*
470	*51*	*0.29*	600	*88*	*0.05*
480	*47*	*0.33*	610	*89*	*0.05*
490	*43*	*0.37*	620	*91*	*0.04*
500	*40*	*0.40*	630	*94*	*0.03*
510	*38*	*0.42*	640	*97*	*0.01*
520	*39*	*0.41*	650	*98*	*0.01*

Wavelength where absorbance is maximum, λ_{max}: _510__ nm

Absorbance at λ_{max}: _0.40_

Attach Absorbance vs. Wavelength Plot.

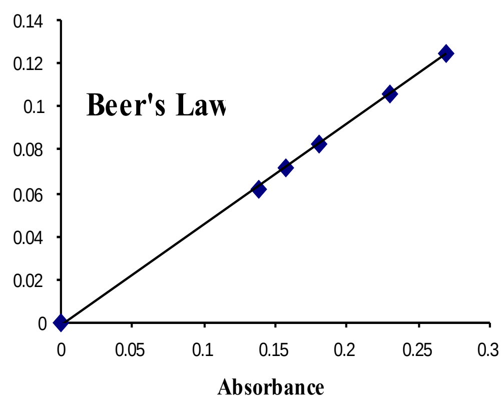
Part B: Measuring Absorbance of Diluted Solutions of Cobalt Chloride

H_2O added mL	Molarity	%Transmittance	Absorbance
0	0.080	*38*	*0.42*
5	0.0533	*52*	*0.28*
10	0.040	*63*	*0.20*
15	0.032	*70*	*0.16*
20	0.0267	*72*	*0.14*

Path length: ___*1.00*___ cm Beer's Law constant, ε : :___*4.84*___ $M^{-1}cm^{-1}$

Attach absorbance vs. Molarity plot for $CoCl_2$ (below is for $NdCl_3$)

from: Excel and equation (y = 0.463 x) of trend line; retaining 2 significant figures.



Part C: Determining the Concentration of an Unknown

Code number/letter of the Unknown: ___*C-1*______
Concentration of the Unknown: _____*0.0325*_____ M

Code number/letter of the Unknown: ____*C-2*______
Concentration of the Unknown: _____*0.0500*_____ M

Code number/letter of the Unknown: ___*C-3*_______
Concentration of the Unknown: _____*0.0750*_.__ M

Answers to Questions:

1. Would you be able to use your data to find the concentration of a 1.00 M solution of Cobalt chloride? Why or why not?
No, because Beer's Law does not hold for such a high concentration. (See ***Background****)*

2. Describe two different ways that could be used to prepare 100 mL of a 0.0400 M solution starting from a stock (100%) solution of 0.080 M $CoCl_2\,6H_2O$ (237.93 g/mol).
a) Mix a50.0 mL stock solution with 50.0 mL distilled water using burette or pipet to measure the volumes.

b) Find the mass in grams needed and use a volumetric flask:
0.040 mol/L x 0.10 L x 237.93 g/mol = 0.952 g
Place 0.95 g $CoCl_2\,6H_2O$ *in a 100 mL volumetric flask and dilute to the mark.*

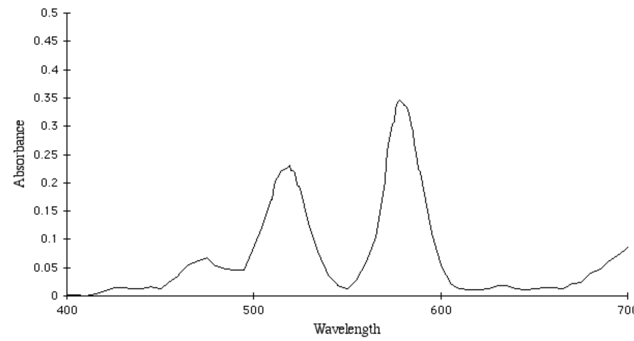
Time: 1 1/2 hours

Equipment and Materials (per group)

Items	**amount/no.**	**Comment**
Wash bottles, distilled water	1	distilled water; to fill blank cuvette and burette
Spectronic-20	1	
Stock 0.080 M $CoCl_2$	50 mL	500 mL for whole class
50 mL burettes	2	One for water, one for $CoCl_2$
Ring stand	1	
Burette clamp	1	
50 ml beaker	4	
Plastic funnel	1	For filling burettes and cuvettes (rinse between uses)
Cuvettes (1 cm tubes)	6	1 for blank; 5 for samples
Cuvette stand	1	
Waste sample bottles	1/class	
Unknown $CoCl_2$ solutions	5 mL	(C-1) 0.0325 M, (C-2) 0.0500 M , (C-3) 0.0750 M (500 mL of each for the whole class)
Safety glasses	1 pair per student	
Rubber gloves	1 pair per student	

Ideas/ Information

1. <u>The Lanthanides</u> The lanthanide ions have interesting visible spectra that arise from electronic transitions among f orbitals. The 4f orbitals involved are effectively shielded from their chemical environments by outer 5s and 5p electrons. As a result the spectra arising from f-f electronic transitions are extremely sharp and are unaffected by the anions. The spectra of $NdCl_3$ and $Nd(NO_3)_3$ are virtually identical.



2. Solutions could be prepared by diluting the stock solution, but it is more convenient to prepare each solution separately. Molar mass of $CoCl_2 \cdot 6H_2O$ is 237.93 g/mol

Molarity mol/L	g for 1 L solution	g for 500 mL solution	g for 100 mL solution
0.080	19.03	9.52	1.90
(C-1) 0.0750	17.84	8.92	1.78
(C-2) 0.0500	11.90	5.95	1.19
(C-3) 0.0325	7.73	3.87	0.77