ANSWER KEY. Readings have small random noise; accept values within about 0.01.

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Beer's Law Virtual Lab

Chemistry and AP Chemistry | ANSWER KEY

Open **activities.zornscience.org/beers-law-lab/** and follow each step. Show your work with units.

Objective

Use a spectrophotometer to find how **absorbance** depends on **wavelength** and on **concentration**, then use a calibration curve to find the concentration of an **unknown**.

NGSS alignment: HS-PS4-4 (supporting). Evaluate claims about the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

Practices and concepts: Planning and carrying out investigations; Analyzing and interpreting data; Using mathematics; Patterns; Scale, proportion, and quantity.

AP alignment: 3.13 Beer-Lambert Law. Skills 2.E (identify sources of experimental error) and 5.F (calculate an unknown quantity from known quantities).

Meet the simulation

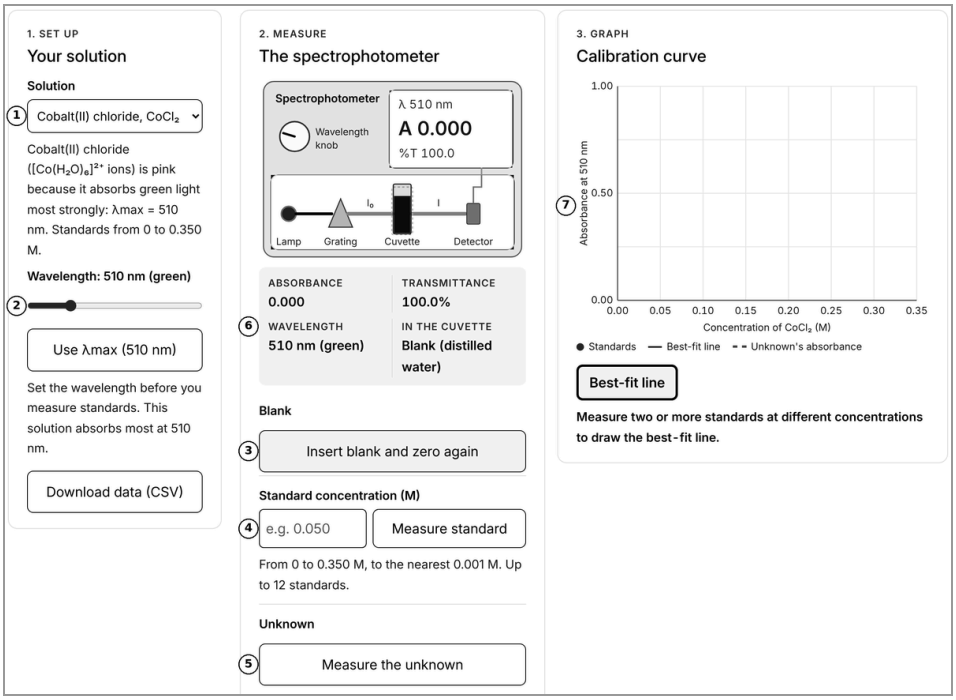


Figure 1. The Beer's Law Spectrophotometer Lab after zeroing. The dark display is shown inverted for printing.

1. Solution menu.
2. Wavelength slider (380 to 950 nm). It locks once you have standards.
3. Inserts the blank (water) and sets A = 0.
4. Type a standard's concentration, then select **Measure standard**.
5. Measures the unknown sample.
6. Readouts: absorbance, transmittance, wavelength, what is in the cuvette.
7. Calibration curve with best-fit line.

Pre-lab

1. Beer's law is A = εbc. Name each variable and its unit.

A = absorbance (no unit); ε = molar absorptivity, L/(mol·cm); b = path length, cm; c = concentration, mol/L (M).

2. A solution has ε = 4.8 L/(mol·cm) in a 1.00 cm cuvette. Predict its absorbance at 0.150 M.

A = εbc = (4.8 L/(mol·cm))(1.00 cm)(0.150 mol/L) = <u>0.72</u>

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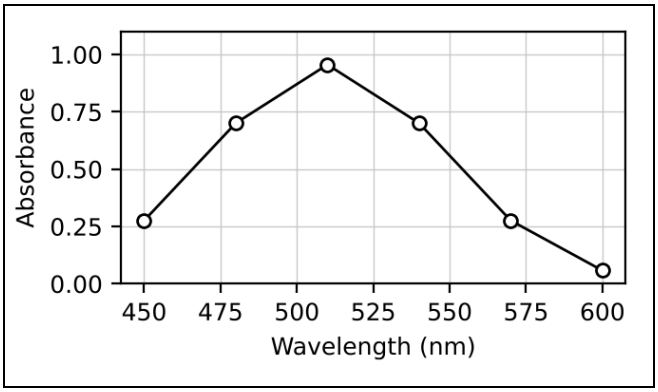
3. Cobalt(II) chloride solution looks pink. Predict which color of light it absorbs most. Explain.

Green light. A solution absorbs the color opposite its own on the color wheel and transmits the rest; pink/red light passes through to your eye.

Part A. Find the best wavelength (λ_{max})

1. Keep Solution = **Cobalt(II) chloride, $CoCl_2$**. Select **Insert blank and zero**.
2. Type **0.200** in the standard box and select **Measure standard**. Then select **Remove** next to Standard 1 in the data table. The 0.200 M sample stays in the cuvette, and the wavelength slider unlocks.
3. Move the slider to each wavelength in the table (use the arrow keys for exact values). Record the absorbance and the light color shown next to the wavelength.

Wavelength (nm)	Light color	Absorbance, 0.200 M
450	**blue**	**0.276**
480	**blue**	**0.701**
510	**green**	**0.956**
540	**green**	**0.701**
570	**yellow**	**0.276**
600	**orange**	**0.058**



Sketch absorbance against wavelength on the grid.

4. What is λ_{max} for $CoCl_2$? Does this support your prediction in question 3?

λ_{max} = 510 nm (green light), the highest absorbance (0.956). Yes, pink $CoCl_2$ absorbs green light most.

5. Why should you measure your standards at λ_{max} instead of at 600 nm?

At λ_{max} the absorbance is largest, so the slope of the calibration line is steepest. A small change in concentration gives a large change in A, so the measurement is most sensitive and least affected by noise. At 600 nm, A = 0.058 for 0.200 M, almost nothing to measure.

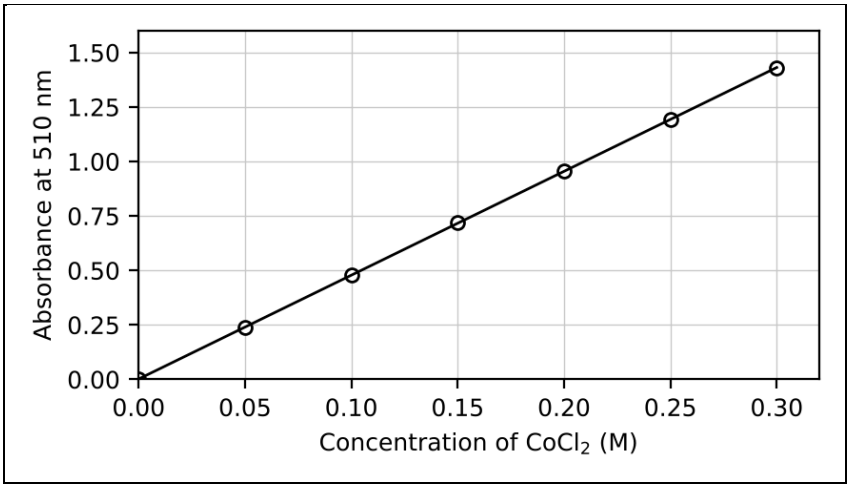
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Part B. Build a calibration curve and find the unknown

1. Select **Use λmax (510 nm)**. Measure standards of **0.050, 0.100, 0.150, 0.200, 0.250** and **0.300 M**, one at a time. Record each absorbance.
2. Select **Measure the unknown** and record its absorbance. (Each student's unknown is different.)

Concentration (M)	0.000 (blank)	0.050	0.100	0.150	0.200	0.250	0.300	Unknown
Absorbance at 510 nm	0.000	**0.240**	**0.479**	**0.718**	**0.956**	**1.194**	**1.429**	**varies**

6. Graph absorbance (y) against concentration (x). Draw a best-fit line and find its slope with two points on your line. Then compare your slope with the equation under the simulation's graph.



Straight line through the origin. Slope = ΔA/Δc = (1.429 − 0.240)/(0.300 M − 0.050 M) = <u>4.76 M^{-1}</u>
The simulation shows about A = 4.76c + 0.00 (R^2 = 0.9999). Slopes from 4.7 to 4.8 are correct.

7. Use your best-fit line to calculate the concentration of your unknown: c = (A − b) / m. Then type it in the box and select **Check my answer**.

Answers vary (the unknown is random, between about 0.05 and 0.30 M). Method: c = ($A_{unknown}$ − b) / m.
Example (Figure 2): A = 0.777, line A = 4.786c + 0.000: c = (0.777 − 0.000) / 4.786 M^{-1} = <u>0.162 M</u>. Correct if the simulation says “Correct” (within 4%).

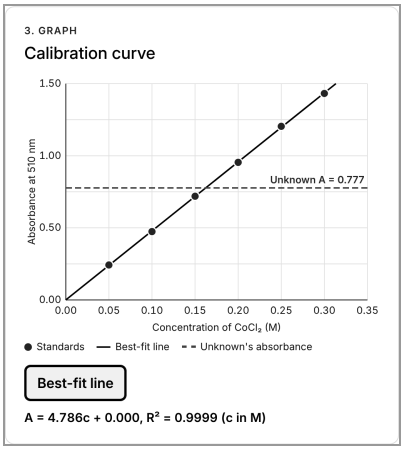


Figure 2. A calibration curve with the unknown's absorbance as a dashed line.

Your unknown's absorbance appears as a dashed line. Where it crosses the best-fit line, read straight down to the concentration axis. That is a graphical check of question 7.

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Analysis

8. The slope of the calibration line equals εb. Use your slope to calculate ε for $CoCl_2$ at 510 nm.

ε = slope / b = 4.76 M^{-1} / 1.00 cm = <u>4.76 L/(mol·cm)</u> (the model uses 4.8; the top standards read slightly low).

9. Clear standards, set the wavelength to **570 nm**, and measure the **0.100** and **0.200 M** standards. Record both absorbances and the new slope. Explain why the slope changed.

A = 0.138 and 0.276; slope = (0.276 − 0.138)/(0.100 M) = <u>1.38 M^{-1}</u>. $CoCl_2$ absorbs yellow light much less than green light, so ε (and the slope εb) is smaller at 570 nm. The curve is still a straight line but less sensitive.

10. (AP extension) Transmittance is $\%T = 100 \times 10^{-A}$. Calculate %T for the 0.200 M standard at 510 nm and at 600 nm. Which wavelength lets more light reach the detector?

510 nm: $\%T = 100 \times 10^{-0.956}$ = <u>11.1%</u>. 600 nm: $\%T = 100 \times 10^{-0.058}$ = <u>87.5%</u>. More light reaches the detector at 600 nm because little is absorbed.

11. (AP extension) Give two errors in a real Beer's law lab and how each changes the calculated concentration of the unknown.

Any two: fingerprints or scratches on the unknown's cuvette raise A, so c is too high; water drops left in the cuvette dilute the sample, so A and c are too low; skipping the blank (not zeroing) adds the cuvette's absorbance to every reading; measuring the unknown at a different wavelength than the standards gives a wrong c; air bubbles scatter light and raise A.

Conclusion

12. Write a claim that answers the objective. Support it with evidence from Parts A and B (specific numbers), then explain your reasoning with Beer's law.

Claim: Absorbance is directly proportional to concentration at a fixed wavelength, and it is largest at λ_{max}, so a calibration curve at λ_{max} can find an unknown's concentration.
Evidence: At 510 nm, A rose from 0.240 to 0.479 to 0.956 as c doubled from 0.050 to 0.100 to 0.200 M (R^2 = 0.9999). The 0.200 M sample read 0.956 at 510 nm but 0.058 at 600 nm. An unknown with A = 0.777 gave 0.162 M (sample answer).
Reasoning: A = εbc. With b and ε fixed, A doubles when c doubles, so the line has slope εb. ε is largest at the color the solution absorbs most.

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