MINI-PROJECT 1 / LEVEL 1 · EASY

The sample that looks too dark

Calibration • dilution • linear functions · Approx. 45–60 min

YOU SEE

A sequence of more concentrated standards looks progressively darker.

The chemical question. Can you report both unknown concentrations without using a calibration beyond the range tested?

1 / FIRST RECOGNIZE THE PROBLEM

- What do the standard solutions hold fixed, and what changes from vial to vial?
- Why does adding water change concentration but not the amount of solute?
- Which observed quantity is an instrument reading, and which is the chemical quantity you want?

2 / WORKING EVIDENCE

A colorimeter was calibrated with five known concentrations of one dissolved dye. Absorbance is dimensionless. The numbers below are **simulated**, chosen so you can examine the reasoning.

Concentration (mM)	0.0	1.0	2.0	3.0	4.0
Absorbance	0.020	0.160	0.300	0.440	0.580

Unknown U: absorbance 0.370. Unknown V: absorbance 0.720. Equal volumes of V and pure water are then mixed; the diluted V reads 0.370.

Working assumption. Use only the measured standard range to claim calibration validity; model extrapolation is a different claim.

MINI-PROJECT 1 / INVESTIGATION

The sample that looks too dark — make a defensible claim

3 / BUILD, CALCULATE, TEST

1. Make the observation visible. Plot the five standards as absorbance versus concentration; mark U and the undiluted V as horizontal reading levels.

2. Build the simplest useful model. Find the slope and baseline, with units where appropriate. Write absorbance as a function of concentration and verify one standard you did not use to find the slope.

3. Find the unknowns. Determine U from its reading. Determine V from its diluted reading, explicitly showing the dilution calculation.

4. Make a decision. Explain why calculating a number from V = 0.720 using the line does not, by itself, justify reporting it as calibrated.

5. Test your answer. Predict the absorbance of the diluted V from your reported original concentration and explain why U and diluted V can have identical readings.

4 / WHAT TO HAND IN

Submit **one concise 1–2 page scientific note** with these components:

- One or two pages containing: a sketch or graph, the model in symbols, enough intermediate calculations to reproduce your result, and a short decision/interpretation.
- State which cognitive pattern you recognized (for example COLLECTION, ARRANGEMENT, DIRECTION, SAMENESS, or CHANGE) and why the chosen mathematics answers the chemical question.
- Include one independent check (units, calibration range, reconstruction, symmetry, or a physically meaningful limiting case).
- You may use a calculator, spreadsheet, or simple plotting program. Explain your own steps; a screenshot of a result is not an explanation.

Proposed rubric (20 pts): recognition 4 · representation 4 · calculation 6 · check/limitation 4 · communication 2.

Scope: This is the take-home part of Exam 1; the in-class test is separate. Every value and observation supplied here is simulated for teaching. Explain what the evidence supports and what it does not.

MINI-PROJECT 2 / LEVEL 2 · EASY+

The reaction that halves

Functions • natural logarithms • local approximation · Approx. 55–70 min

YOU SEE

The same interval passes; the remaining amount shrinks by the same factor.

The chemical question. What mathematical description explains a constant fractional loss, and when is a short polynomial an acceptable shortcut?

1 / FIRST RECOGNIZE THE PROBLEM

- Do equal five-minute intervals remove equal amounts or equal fractions?
- What does a straight line hide or reveal when you change what is on the vertical axis?
- Why should a local approximation be checked before using it for a longer time?

2 / WORKING EVIDENCE

A dissolved species A disappears during a simplified reaction. The following simulated concentration observations are exact for this teaching model.

Time (min)	0	5	10	15
[A] (M)	0.800	0.400	0.200	0.100

For this project, use the model $[A](t) = [A]_0 \exp(-kt)$. Use a **dimensionless** ratio inside the logarithm. An exponent of -0.10 corresponds to a short time interval $\Delta t = 0.10/k$. Compare $\exp(-0.10)$ with $1 - 0.10$ and $1 - 0.10 + (0.10)^2/2$.

Working assumption. These data support a useful mathematical model; they do not independently prove a molecular reaction mechanism.

MINI-PROJECT 2 / INVESTIGATION

The reaction that halves — make a defensible claim

3 / BUILD, CALCULATE, TEST

1. Recognize the pattern. Compute successive differences and successive ratios. Decide whether a straight line in ordinary [A] versus time is a suitable model.

2. Change the representation. Plot or tabulate $\ln([A]/[A]_0)$ against time. Extract k, state its units, and explain the meaning of the negative slope.

3. Predict. Estimate [A] at 12 min from the model; check that your prediction lies between the 10- and 15-minute observations.

4. Approximate locally. Evaluate the linear and quadratic approximations to $\exp(-0.10)$, compare each to your calculator, and decide which achieves absolute error below 0.001.

5. State a boundary. Explain why an approximation tested at -0.10 should not be assumed accurate at -2.

4 / WHAT TO HAND IN

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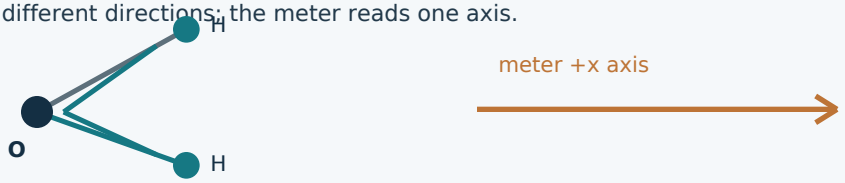
MINI-PROJECT 3 / LEVEL 3 · EASY–MEDIUM

The dipole and the fixed meter

Vectors • components • dot products • matrix multiplication · Approx. 60–75 min

YOU SEE

Two bond contributions point in different directions; the meter reads one axis.



The chemical question. Why can turning an unchanged molecule change what a fixed directional sensor measures?

1 / FIRST RECOGNIZE THE PROBLEM

- Which parts of the molecular description are lengths, and which are directions?
- Does changing the direction of the whole molecule change its internal geometry?
- If the meter and molecule both turn together, what should remain the same?

2 / WORKING EVIDENCE

Model water in a 2-D drawing: O = (0,0), H_1 = (0.80, 0.60) Å, H_2 = (0.80, −0.60) Å. Assign each O→H bond a dipole contribution of magnitude **1.50 D**, directed along its bond. This is an idealized vector model, not a measured water dipole.

Object	x coordinate / component	y coordinate / component
O	0.00 Å	0.00 Å
H_1	+0.80 Å	+0.60 Å
H_2	+0.80 Å	−0.60 Å

The meter reads the dot product of the total dipole with a fixed unit sensing direction e_x = (1,0). The molecule is rotated **90° counterclockwise** using the matrix R = [[0, −1], [1, 0]].

Working assumption. No 3-D rotation formula is needed. The 2-D model isolates the role of direction and representation.

MINI-PROJECT 3 / INVESTIGATION

The dipole and the fixed meter — make a defensible claim

3 / BUILD, CALCULATE, TEST

1. Draw before computing. Sketch both O→H vectors, their individual dipole contributions, and the fixed +x meter direction.

2. Add the physical contributions. Find each bond unit vector, each bond dipole vector, and the total dipole μ. Give components and magnitude in D.

3. Let a matrix act. Multiply Rμ. Then separately compute $R\mu_1 + R\mu_2$ and compare with $R(\mu_1 + \mu_2)$.

4. Ask what the meter reads. Compute $\mu \cdot e_x$ before rotation and $(R\mu) \cdot e_x$ after rotation.

5. Test what stays the same. Check the dipole magnitude before and after; now rotate the sensing direction by R too and recompute the dot product. Explain the difference between turning the molecule and merely redescribing the same geometry.

4 / WHAT TO HAND IN

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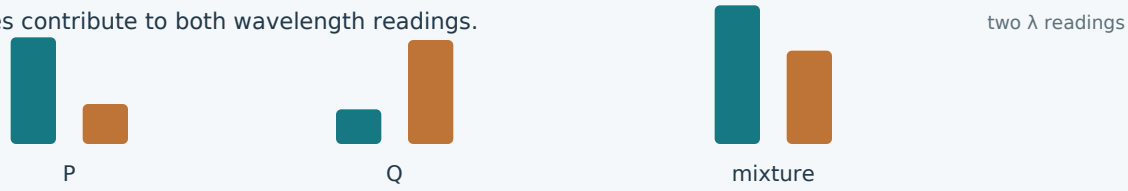
MINI-PROJECT 4 / LEVEL 4 · MEDIUM

Two colors, two readings

Coupled measurements • linear equations • matrix multiplication · Approx. 65–80 min

YOU SEE

Both substances contribute to both wavelength readings.



The chemical question. When two substances both affect both signals, can two instrument readings distinguish their amounts?

1 / FIRST RECOGNIZE THE PROBLEM

- What is mixed physically, and what is mixed in the instrument response?
- Why can the reading at one wavelength be explained by several different mixtures?
- What does the row-by-column product actually calculate?

2 / WORKING EVIDENCE

A sample contains dyes P and Q. A detector reads absorbance at wavelengths λ_1 and λ_2. For this simulated linear model, the calibration sensitivities (in mM^{-1}) are:

Wavelength	Effect of 1 mM P	Effect of 1 mM Q
λ_1	0.40	0.10
λ_2	0.15	0.30

Three prepared controls contain (P,Q) in mM: C_1 = (2,0), C_2 = (0,2), C_3 = (2,1). A blinded mixture produces the readings (A_1, A_2) = (0.90, 0.60). Absorbance is dimensionless.

Working assumption. Stay within matrix multiplication and two simultaneous linear equations. Matrix inverse and determinant are not needed.

MINI-PROJECT 4 / INVESTIGATION

Two colors, two readings — make a defensible claim

3 / BUILD, CALCULATE, TEST

1. Draw the coupling. Sketch arrows from both dyes to both wavelength readings; explain why a single calibration line for P would not suffice.

2. Represent the mapping. Form the 2×2 sensitivity matrix M and a 2×3 concentration matrix C whose columns are the three controls. Label rows, columns, and units.

3. Multiply with meaning. Compute MC by row-by-column multiplication. Explain one product entry in a complete chemical sentence.

4. Solve the blind mixture. Write the two simultaneous equations and solve by substitution or elimination. Verify your concentrations by multiplying M by your result.

5. Expose a tempting error. If you pretend Q does not absorb at λ_1, what P concentration would you report? Compare it with the two-wavelength result and explain the discrepancy.

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