

Mechanisms, catalysts and activation energy

AP Chemistry · Worksheet

Name: _____ Date: _____ Class: _____

These problems cover elementary steps, rate-determining steps, energy profiles, catalysts and the Arrhenius equation. They progress from naming species and reading diagrams to testing proposed mechanisms and handling activation-energy calculations. They follow the style of AP Chemistry Unit 5 and first-year university kinetics; give units with every numerical answer.

Level: AP Chemistry · **Curriculum:** AP Chem Unit 5

Problem 1 Molecularity and rate laws (easy)

Classify each elementary step and write its rate law.

1. $\text{O}_3 \rightarrow \text{O}_2 + \text{O}$
2. $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$
3. $2 \text{NO}_2 \rightarrow \text{N}_2\text{O}_4$

Problem 2 Naming the species (easy)

In a mechanism, species X is formed in step 1 and consumed in step 2, while species Y is consumed in step 1 and re-formed in step 2.

1. Name each species.
2. State whether X or Y appears in the overall equation.
3. Name the species at the top of an energy-profile peak.

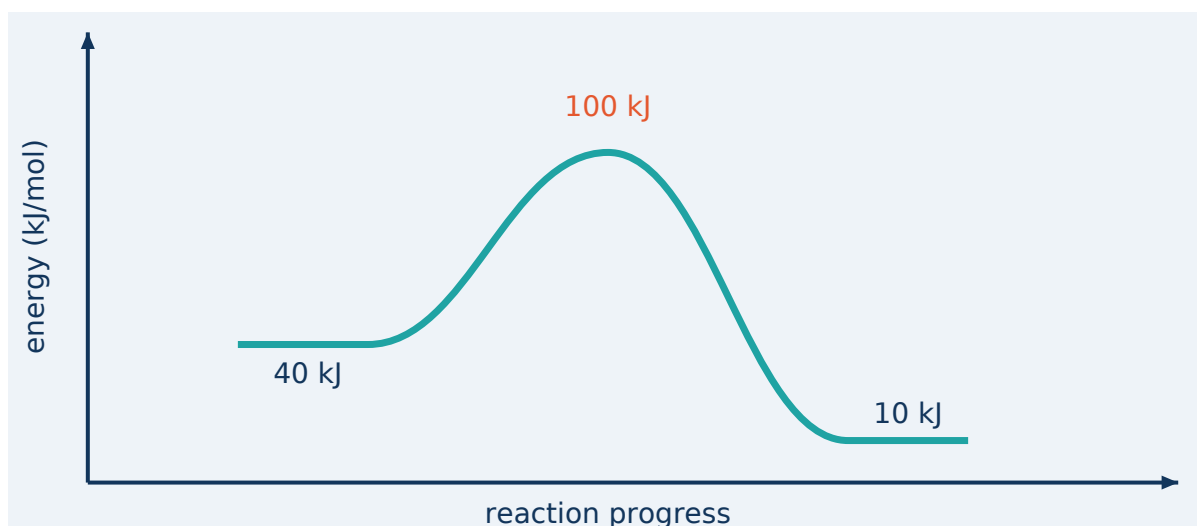
Problem 3 Adding the steps (easy)

Bilal in Lahore proposes: step 1, $\text{Cl} + \text{O}_3 \rightarrow \text{ClO} + \text{O}_2$; step 2, $\text{ClO} + \text{O} \rightarrow \text{Cl} + \text{O}_2$.

1. Write the overall equation.
2. Identify the catalyst and the intermediate.

Problem 4 Reading an energy diagram (easy)

Use the profile.



Energies are relative to a common zero.

1. Calculate E_a for the forward reaction.
2. Calculate ΔH .
3. Calculate E_a for the reverse reaction.

Problem 5 True or false about catalysts (easy)

State whether each is true or false and correct the false ones.

1. A catalyst changes ΔH .
2. A catalyst lowers the activation energy.
3. A catalyst shifts the equilibrium to the product side.
4. A catalyst is used up in the reaction.

Problem 6 Slow step and rate law (easy)

$A + 2 B \rightarrow D$ proceeds by: step 1 (slow) $A + B \rightarrow C$; step 2 (fast) $C + B \rightarrow D$.

1. Show that the steps give the overall equation.
2. Identify the intermediate.
3. Write the predicted rate law.

Problem 7 Why heat speeds reactions (easy)

Explain, in terms of collisions, why a reaction in a pressure cooker at 120 °C is much faster than in an open pan at 100 °C.

Problem 8 Checking a mechanism for nitric oxide (medium)

The reaction $2 NO + 2 H_2 \rightarrow N_2 + 2 H_2O$ has a mechanism: step 1 (slow) $2 NO + H_2 \rightarrow N_2 + H_2O_2$; step 2 (fast) $H_2O_2 + H_2 \rightarrow 2 H_2O$.

1. Show that the steps add to the overall equation.
2. Identify the intermediate.
3. Predict the rate law and its overall order.

Problem 9 Choosing between mechanisms (medium)

For $2A + B \rightarrow C$, experiment gives rate = $k[A][B]$. Mechanism I: (slow) $A + B \rightarrow X$; (fast) $X + A \rightarrow C$. Mechanism II: (slow) $2A \rightarrow Y$; (fast) $Y + B \rightarrow C$.

1. Predict the rate law for each.
2. State which mechanism fits the data.
3. Explain why the data cannot prove that mechanism.

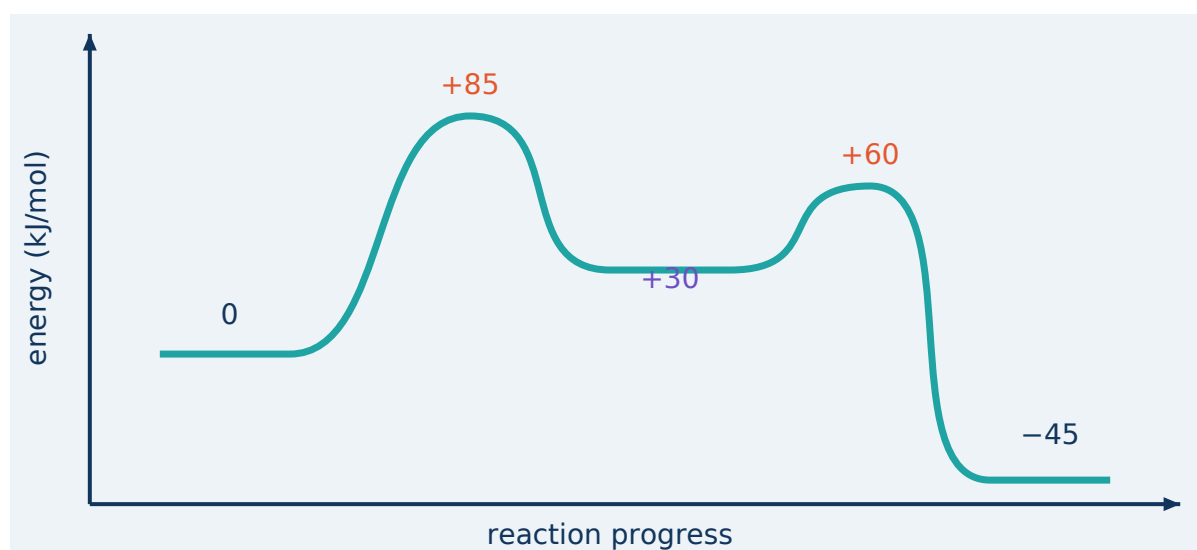
Problem 10 Fast equilibrium first (medium)

$A + B \rightleftharpoons AB$ is a fast equilibrium with $K = 4.0 \text{ M}^{-1}$, followed by a slow step $AB + B \rightarrow C$ with $k_2 = 0.50 \text{ M}^{-1} \text{ s}^{-1}$.

1. Write the overall equation.
2. Derive the rate law in terms of $[A]$ and $[B]$.
3. Calculate the observed rate constant and the rate when $[A] = 0.10 \text{ M}$ and $[B] = 0.20 \text{ M}$.

Problem 11 Two-step profile (medium)

Use the energy values on the diagram.



Energies in kJ/mol relative to the reactants.

1. Calculate E_a for step 1 and step 2.
2. Identify the rate-determining step.
3. Calculate ΔH overall.
4. Calculate E_a for the reverse of step 1.

Problem 12 Catalyst and rate constant (medium)

A reaction has $E_a = 75 \text{ kJ/mol}$. A catalyst gives a new path with $E_a = 50 \text{ kJ/mol}$. Assume A is unchanged and $T = 298 \text{ K}$.

1. Calculate the factor by which k increases.
2. State what happens to the rate of the reverse reaction.

3. State what happens to ΔH .

Problem 13 Activation energy from a rule of thumb (medium)

A reaction's rate constant doubles when the temperature rises from 300 K to 310 K.

1. Calculate E_a .
2. Give your answer in kJ/mol.

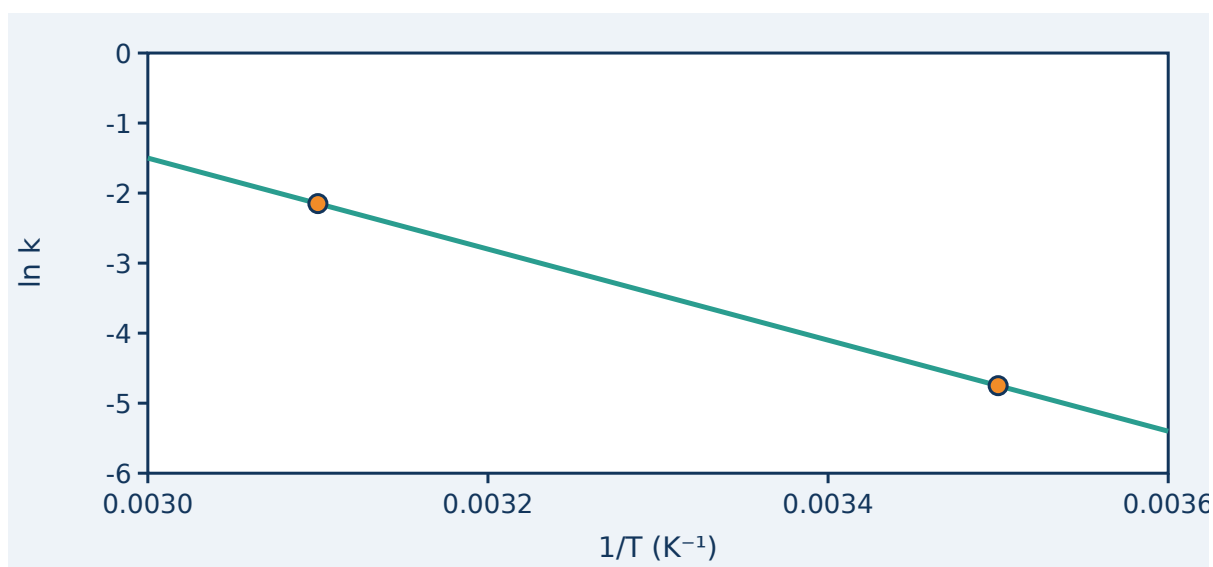
Problem 14 Predicting a rate constant (medium)

A reaction has $E_a = 80.0$ kJ/mol and $k = 1.5 \times 10^{-5} \text{ s}^{-1}$ at 298 K.

1. Calculate k at 318 K.
2. Calculate how many times faster the reaction runs at 318 K.

Problem 15 Reading an Arrhenius plot (medium)

The graph is for a gas-phase reaction.



The marked points are (0.0031, -2.15) and (0.0035, -4.75).

1. Calculate the slope.
2. Calculate E_a in kJ/mol.
3. Find $\ln A$ and A .

Problem 16 Catalytic decomposition of peroxide (hard)

Iodide ions catalyse $2 \text{ H}_2\text{O}_2 \rightarrow 2 \text{ H}_2\text{O} + \text{O}_2$ by: step 1 (slow) $\text{H}_2\text{O}_2 + \text{I}^- \rightarrow \text{H}_2\text{O} + \text{IO}^-$; step 2 (fast) $\text{H}_2\text{O}_2 + \text{IO}^- \rightarrow \text{H}_2\text{O} + \text{O}_2 + \text{I}^-$.

1. Show the steps add to the overall equation.
2. Identify the catalyst and the intermediate.
3. Write the rate law and explain why it is not second order in H_2O_2 even though two molecules appear in the equation.
4. Calculate the rate when $k = 0.0115 \text{ M}^{-1} \text{ s}^{-1}$, $[\text{H}_2\text{O}_2] = 0.50 \text{ M}$ and $[\text{I}^-] = 0.020 \text{ M}$.

Problem 17 Designing an experiment (hard)

For $2A + B \rightarrow C$, mechanism X predicts rate = $k[A]^2$ and mechanism Y predicts rate = $k[A]^2[B]$.

1. Describe an experiment that distinguishes them.
2. State the result expected from each mechanism.
3. Data: $[A] = 0.10\text{ M}$, $[B] = 0.10\text{ M}$ gives rate $1.2 \times 10^{-3}\text{ M/s}$; $[A] = 0.10\text{ M}$, $[B] = 0.30\text{ M}$ gives $3.6 \times 10^{-3}\text{ M/s}$. Decide which mechanism is supported and calculate k .
4. Explain why this evidence supports but does not prove the mechanism.

Problem 18 Food spoilage and temperature (hard)

A spoilage reaction in milk has $E_a = 65\text{ kJ/mol}$.

1. Calculate the ratio of rate constants at 25°C and 4°C .
2. Milk stays fresh for 4.0 days in a refrigerator at 4°C . Predict how long it stays fresh at 25°C , assuming spoilage is controlled by this reaction.

Problem 19 Matching a catalysed rate (hard)

An uncatalysed reaction has $E_a = 100\text{ kJ/mol}$; a catalyst reduces it to 60 kJ/mol . Assume the same A.

1. Calculate the increase in k caused by the catalyst at 300 K .
2. Calculate the temperature at which the uncatalysed reaction has the same k as the catalysed one at 300 K .
3. Explain why using a catalyst can be preferable to heating.

Problem 20 Surface catalysis and zero order (hard)

The decomposition of N_2O on a hot gold surface is first order at low pressure and zero order at high pressure.

1. Explain the zero-order behaviour using the surface.
2. Describe how the plot of rate against $[\text{N}_2\text{O}]$ looks.
3. In the zero-order region, $k = 3.0 \times 10^{-5}\text{ M/s}$ and $[\text{N}_2\text{O}]_0 = 0.012\text{ M}$. Calculate the time to finish if the order stays zero.
4. Explain why the reaction slows down at the end.