AP Chemistry Unit 5 Topic 5.4: Zero-Order Reactions

Complete Study Guide with All Answers

📚 What You'll Master:

- ✓ **Quick Knowledge Check:** Review Unit 5 fundamentals
- ✓ **Zero-Order Definitions:** Rate laws & key characteristics
- ✓ **Graph Mastery:** Identify zero-order with the straight line test
- ✓ **Real-World Analogies:** Coffee shops & assembly lines
- ✓ **Practice Problems:** Complete solutions for all questions

💡 This guide is 100% static - all answers included for easy study!

✏️ Prepared by: **Mr. Hisham Mahmoud**

Master Chemistry with Confidence

🧠 Quick Knowledge Check: Unit 5 Foundations

Review these foundational concepts before starting Zero-Order Reactions.

Question 1: Rate Expression Fundamentals ⚗️

Scenario: For the reaction: $2NO_2(g) + F_2(g) \rightarrow 2NO_2F(g)$

Experimental data shows that doubling $[NO_2]$ quadruples the rate, while doubling $[F_2]$ doubles the rate.

What is the correct rate law expression?

✅ **Answer: B) Rate = $k[NO_2]^2[F_2]$**

📘 **Explanation:**

Since doubling $[NO_2]$ quadruples the rate ($2^2 = 4$), the reaction is **second order** with respect to NO_2.

Since doubling $[F_2]$ doubles the rate ($2^1 = 2$), the reaction is **first order** with respect to F_2.

Therefore, the rate law is Rate = $k[NO_2]^2[F_2]^1$.

Question 2: Method of Initial Rates 📊

Given this data table:

Experiment	[A] (M)	[B] (M)	Initial Rate (M/s)
1	0.10	0.10	0.015
2	0.20	0.10	0.030
3	0.10	0.20	0.060

What is the order of the reaction with respect to reactant B?
Hint: Compare experiments 1 and 3 where [A] stays constant.

✅ **Answer: C) Second order (m = 2)**

📘 **Explanation:**

Compare Experiment 1 and 3 where [A] is constant (0.10 M).
Concentration of [B] doubles (0.10 → 0.20).
Rate quadruples (0.015 → 0.060).
Since the rate increases by a factor of 4 when concentration doubles ($2^x = 4$), x must be 2.

Question 3: Rate Constant Units 🔢

Critical Understanding: The units of the rate constant (k) depend on the **overall reaction order**.

If a reaction has the rate law: Rate = $k[A]^2[B]$

What are the correct units for k?

✅ **Answer: D) $M^{-2}s^{-1}$**

📘 **Explanation:**

The overall order is 2 + 1 = 3 (Third Order).

Rate always has units M/s.

$M/s = k \times (M)^2 \times (M)$

$M/s = k \times M^3$

$k = (M/s) / M^3 = M^{-2}s^{-1}$

1 What is a Zero-Order Reaction?

🎯 Definition

A **zero-order reaction** is one where the rate is *independent* of the concentration of the reactant. The reaction proceeds at a constant speed regardless of how much reactant is present.

$$\text{Rate} = k[A]^0 = k$$

Since any number to the power of 0 is 1, the rate simply equals the rate constant **k**.

☕ The Coffee Shop Analogy

Imagine a coffee shop with one barista. Whether there are 5 customers or 50 customers in line, the barista can only make coffee at one constant speed (e.g., 1 cup every 3 minutes).

The limiting factor is the worker, not the number of customers.

Similarly, in a zero-order reaction, the catalyst (worker) is saturated. Adding more reactant (customers) does not speed up the reaction.

Key Characteristics

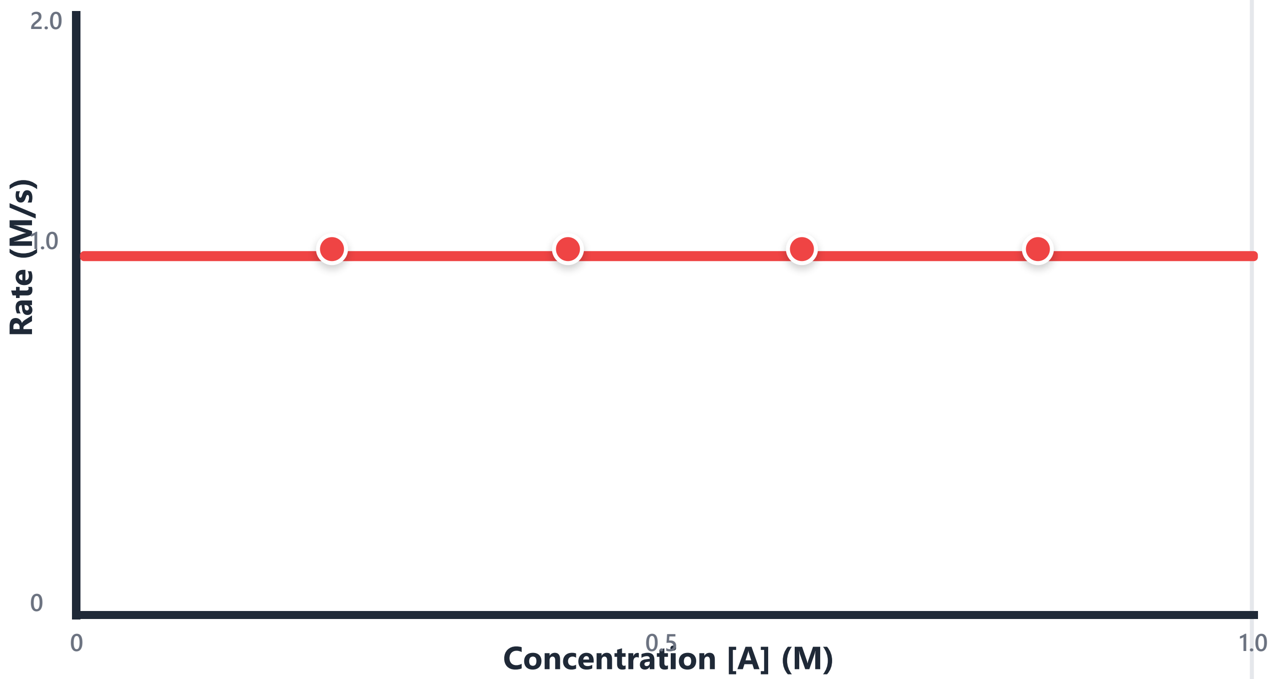
Property	Zero-Order Feature
Rate Law	Rate = k
Rate vs. Concentration	Constant (Horizontal Line)
Units of k	M/s (Molarity per second)

Property	Zero-Order Feature
Real Examples	Enzyme-catalyzed reactions (saturated), Alcohol metabolism in liver, Photochemical reactions

2 Visualizing Zero-Order Reactions

1. Rate vs. Concentration Graph

If you plot Rate on the Y-axis and Concentration [A] on the X-axis:



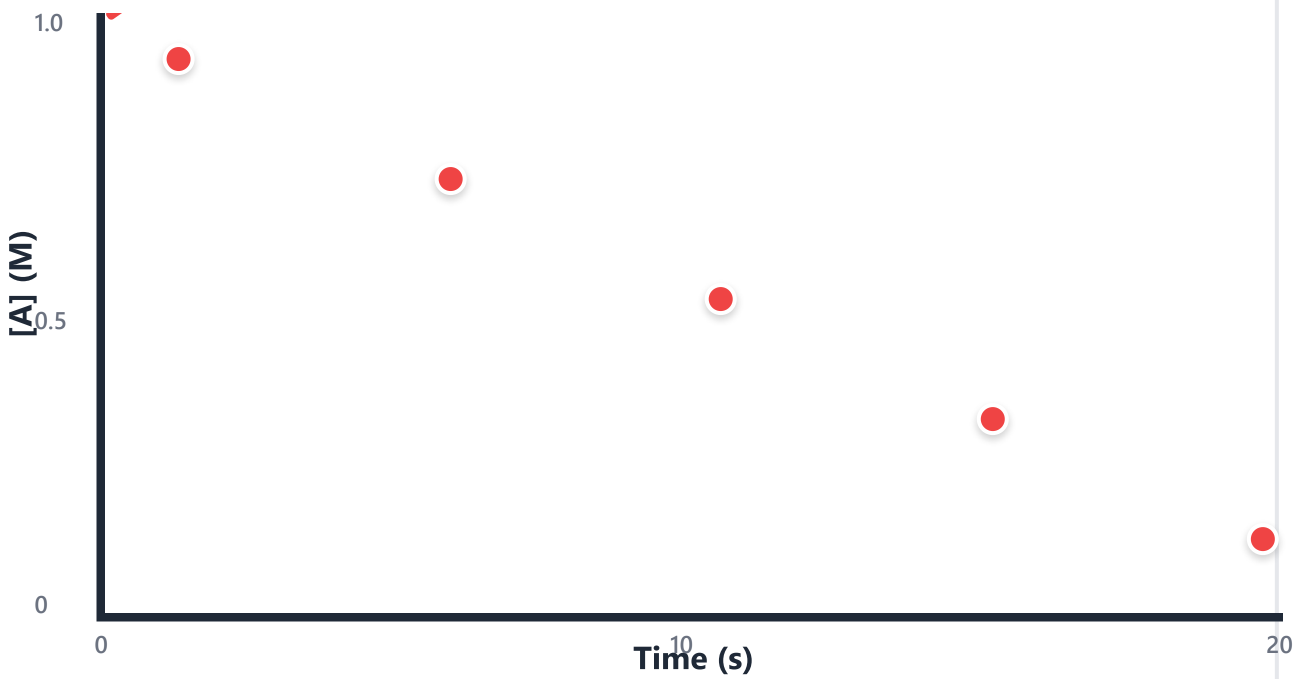
📊 **Observation:** The line is perfectly horizontal at Rate = k. No matter what concentration you have, the rate remains constant!

📘 **Explanation:**

Since Rate = k, the rate is a constant value. It does not change whether [A] is 0.1 M or 10.0 M.

⭐ 2. Concentration [A] vs. Time Graph (MOST CRITICAL)

If you plot Concentration [A] on the Y-axis and Time on the X-axis:



📊 **Observation:** A perfectly STRAIGHT, declining line. This is THE signature of a zero-order reaction - linear decrease over time!

⚠️ **MEMORIZE THIS: A STRAIGHT LINE on an [A] vs. Time graph is the unique fingerprint of a Zero-Order Reaction.**

Graph Properties:

📉 **Shape:** Straight Line
📐 **Slope:** Slope = -k
📍 **Y-Intercept:** $[A]_0$ (Initial Concentration)
📝 **Equation:** $[A] = [A]_0 - kt$

3 The Assembly Line Analogy

🏭 Factory Assembly Line

👷 Imagine a factory worker packing boxes. The worker operates at a strict rhythm: **1 box every 2 seconds.**

Scenario A: 5 boxes are waiting on the belt.
Result: Worker packs 1 box every 2 seconds.

Scenario B: 500 boxes are waiting on the belt.
Result: Worker still packs 1 box every 2 seconds.

Chemistry Translation:

Worker = Catalyst (Enzyme or Metal Surface)
Boxes = Reactant Molecules
Packing Rate = Reaction Rate (k)

Insight: Zero-order reactions occur when the catalyst is working at **maximum capacity** (saturated). Adding more reactant (boxes) cannot speed up the process because the "worker" is already busy.

Comparing Orders by Graph Shape

Order	Graph of [A] vs Time
Zero Order	**Straight Line** 📉 (Linear decay)
First Order	Curved Line (Exponential decay)
Second Order	Deeply Curved Line

📋 Quick Summary: Zero-Order Reactions

🔑 Key Formula

$$Rate = k$$

Concentration has NO effect on rate!

📊 Graph Test

Plot [A] vs Time

See STRAIGHT LINE? ✓ Zero-Order!

📐 Important Equations

Integrated Rate Law:

$$[A] = [A]_0 - kt$$

Units of k:

M/s or M/min

🎓 Final Mastery Quiz

Test your understanding of zero-order kinetics. All answers are provided below each question!

Question 1: Calculation 💡

A reaction follows zero-order kinetics with **k = 0.050 M/s**. The initial concentration is **$[A]_0$ = 0.80 M**.

What will the concentration of A be after 10 seconds?

✅ **Answer: 0.30 M**

📘 **Explanation:**

Use the integrated rate law for zero-order reactions:

$[A] = [A]_0 - kt$

Substitute the values:

[A] = 0.80 M - (0.050 M/s)(10 s)

[A] = 0.80 - 0.50

[A] = 0.30 M

Question 2: Graph Interpretation 📊

You conduct an experiment and plot concentration vs. time. The graph shows a perfectly **straight line** with a slope of **-0.025 M/s**.

What is the rate constant k for this zero-order reaction?

✅ **Answer: A) k = 0.025 M/s**

📘 **Explanation:**

For a zero-order reaction graph ([A] vs Time):
Slope = -k

Given Slope = -0.025
-k = -0.025
k = 0.025 M/s

Question 3: Critical Thinking 🤔

A reaction follows zero-order kinetics. You run two experiments:

• Experiment 1: $[A]_0 = 1.0$ M

• Experiment 2: $[A]_0 = 2.0$ M (doubled)

What happens to the initial rate in Experiment 2 compared to Experiment 1?

✅ **Answer: C) The rate stays exactly the same**

📘 **Explanation:**

This is the defining definition of a zero-order reaction.

Rate = $k[A]^0 = k(1) = k$.

The rate is **independent** of the concentration. Doubling, tripling, or halving the concentration has **zero effect** on the speed of the reaction.

🎉🏆🎓

Congratulations!

You've mastered Zero-Order Reactions! You now understand how these unique reactions
maintain constant rates regardless of concentration. Keep up the excellent work! 🚀

📚 apchemistryrescue.com

Your trusted resource for AP Chemistry success

Prepared with care by **Mr. Hisham Mahmoud**
