NAME _____ DATE _____

Performance Task: Concentration vs. Time

Goal of task

Target concept: Understand reaction rates in both qualitative and quantitative terms

For this task you will be evaluated on your ability to:

- Construct an appropriate graph of concentration vs. time
- Use the graphs to determine the reaction order
- Determine the rate constant from the slope of the appropriate graph and the corresponding rate equation
- Collect data, generate a graph and draw conclusions regarding the kinetics of a reaction.

Task summary

The rate at which a chemical reaction occurs depends upon several factors. In this task you will study how the concentration of the reactant affects the rate of a chemical reaction. The rate of a reaction is typically measured by determining how much the concentration of a reactant changes over a specific time period. The changes in concentration can be measured by recording changes in color, mass or volume. One method of analyzing this data is to graph the reactant concentration vs. time. In this task you, or someone in your group, will graph concentration vs. time for three different chemical reactions and use the graph to determine the reaction order, rate constant and rate equation. You will then use the skills you have learned to make predictions regarding data you will collect for the burning of a candle.

Task 1: Graph reaction data (Individual or group)

The following sets of data were collected for three different decomposition reactions. The reaction was initiated and the concentration of the reactant was measured at 10 minute time intervals and recorded. The data is below:

1. For each set of concentration – time data construct a properly labeled graph of concentration vs. time and draw the best fit curve.

Reaction 1: A ⟶ products – Zero Order	
Time (min)	**Concentration [A] mol/L**
10	0.685
20	0.620
30	0.555
40	0.490
50	0.425
60	0.360
70	0.295
80	0.230
90	0.165
100	0.100

Reaction 2: B ⟶ products – First Order	
Time (min)	**Concentration [B] mol/L**
10	0.293
20	0.254
30	0.220
40	0.191
50	0.165
60	0.143
70	0.124
80	0.107
90	0.0928
100	0.0804

Reaction 3: C ⟶ products – Second Order	
Time (min)	**Concentration [C] mol/L**
10	0.449
20	0.351
30	0.288
40	0.244
50	0.212
60	0.187
70	0.167
80	0.152
90	0.138
100	0.127

2. Examine the three plots and describe how the concentration changes as a function of time for each.

For reaction 1 — the reaction labeled zero order:

3. Determine the slope of the line, including units.
4. What does the slope of the line represent?
5. Does the rate of change in concentration for this reaction depend on the concentration of the reactant? Justify your answer.
6. For reaction 2 — the reaction labeled first order, determine the slope of the line tangent (with units) to the curve at 30, 50 and 70 minutes.
7. Describe how the value of the tangent changes as time progresses. The slope of the tangent line has units of moles/L•min. What does the tangent slope represent?
8. Describe how the rate of the reaction changes as a function of the concentration of the reactant.

9. For reaction 3, the reaction labeled second order, determine the slope of the line tangent (with units) to the curve at 30, 50 and 70 minutes. Describe how the value of the tangent changes as time progresses. The slope of the line has units of moles/L $^{-1}$min^{-1}.
10. Describe how the rate of the reaction changes as a function of reactant concentration.

Check your understanding

As a group, use your three plots to answer the next three questions.

- ☐ In which plot does the rate of the reaction not depend upon concentration? How do you know?
- ☐ What do the tangents drawn represent? How do they change as time progresses?
- ☐ Which plot represents the reaction in which the rate had the greatest change during the time studied? How do you know?

Task 2: Using graphs to find reaction order and rate constant (Individual or group)

In your groups:

1. Compare the slopes of the original lines (or tangent lines) you have drawn on the graphs for reaction 2 and reaction 3 and interpret them in terms of how fast the reaction proceeds at each point. How quickly the concentration changes with time measures how fast the reaction proceeds, which is known as the rate of the reaction.

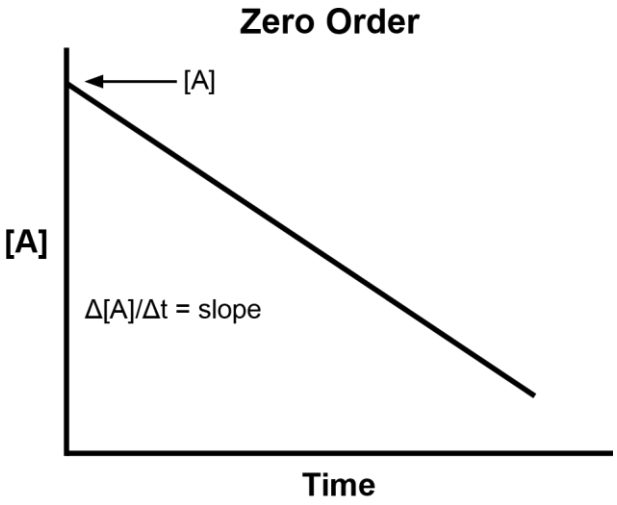
   The rate equation describes how the rate of a chemical reaction depends upon the concentration of the reacting species. It takes the general form Rate = k[A]^{m}. The variable k is the rate constant and [A] is the concentration of the reactant and the m, the exponent, is the order of the reaction.

   Examine the plot of the zero order reaction. As you previously determined the rate of the reaction does not depend upon the concentration of the reactant. The rate at which the reactant is consumed is constant.

   Based on these factors, propose a rate equation for the zero order reaction. Why do you think it is called a zero order reaction?

The concentration vs. time graphs of first and second order reactions are not straight lines. They both curve, although one curves more than the other. Regardless, it would be difficult to distinguish a first order from a second order reaction from a graph of concentration vs. time and impossible to determine the rate constant. Chemists often find it useful to manipulate data to obtain straight line graphs. Using calculus, the integrated rate equation is employed to obtain these graphs. While this integrated rate equation comes from calculus, knowledge of calculus is not required to derive or use the equation in AP Chemistry.

For the zero order reaction you determined that the rate law was Rate = $k[A]^{\circ}$, which simplifies to Rate = k. From Calculus, the integrated rate law is $[A]_t = -kt + [A]_0$, where $[A]_0$ is the initial concentration of the reactant and $[A]_t$ is the concentration of A at time, t. Note that y=mx + b and the graph of [A] vs. time is a straight line with slope = $-k$ and the y-intercept is the initial concentration, A_0. The sketch of a zero order reaction is below.



The Table summarizes the Rate Laws and Integrated Rate Equations for the three reactions we are studying.

	Zero Order	First Order	Second Order
Rate Law	Rate = k	Rate = $k[A]^1$	Rate = $k[A]^2$
Integrated Rate Equation	$[A]_t = -kt + [A]_0$	$\ln[A]_t = -kt + \ln[A]_0$	$\frac{1}{[A]_1} = kt + \frac{1}{[A]_0}$

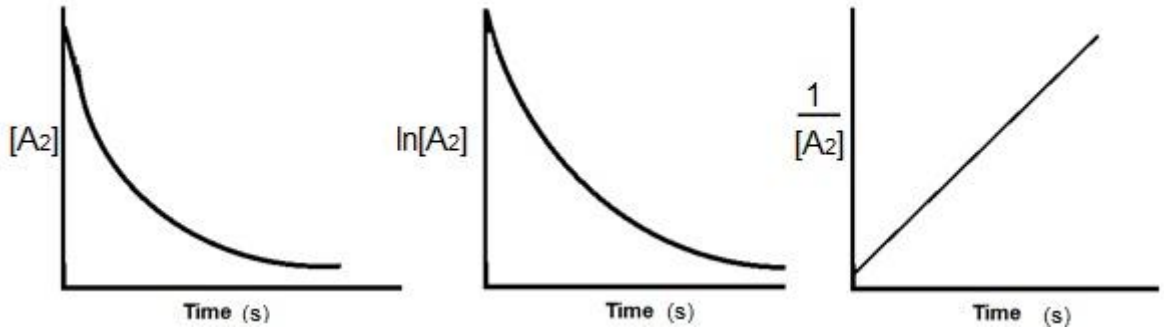
2. For the first and second order reactions, individually sketch a graph of their integrated rate laws on the axes below. Be sure to label the axes, the y-intercept and the slope.

First Order

Second Order

Once you have completed your sketches, share your graphs with your group and then discuss your findings with the whole class. After the group or class discussion proceed to the next question on your own.

3. A student has collected data for the disappearance of A_2 in an experiment to determine the rate law for a reaction and has produced the following graphs from the data:



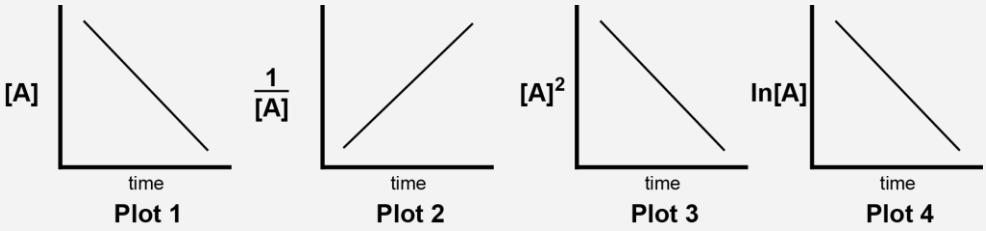
   a. What is the order of the reaction, $A_2 \rightarrow 2A$?

   b. Write the rate law for the reaction.

   c. What would the units be for the rate constant?

Check your understanding

Use the following plots to answer the next three questions.



- ☐ Which plot represents a zero order, a first order and a second order reaction? Explain your reasons for your choices.
- ☐ Provide the rate law for Plot 4 and label the graph to identify the rate constant.
- ☐ Compare the rate of disappearance of A in Plot 1 vs. Plot 2. How is the rate different? Explain your reasoning.

Task 3: Make predictions

Scenario

A burning candle is an example of a reaction that is easy to study. In your group discuss ways you could measure this process and what you would need to do to determine the rate of the reaction.

We want to measure the rate for the combustion reaction in burning a candle (candle + oxygen → carbon dioxide (g) + water (g)

1. What variable could we measure to determine the rate of this reaction?
2. What measurements will we need to take to determine rate?
3. List the materials you will need to perform the experiment.

Construct a data table.

Time (s)	Mass of Candle (g)
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	

4. Describe how you will manipulate the data to determine the rate of the reaction and the rate law.

After taking about 5 minutes to answer the questions above, share your experimental design with your group. Then the teacher will check your procedure before your group proceeds.

5. Collect your data following the procedure you have developed and determine the rate law and rate of burning for your candle.