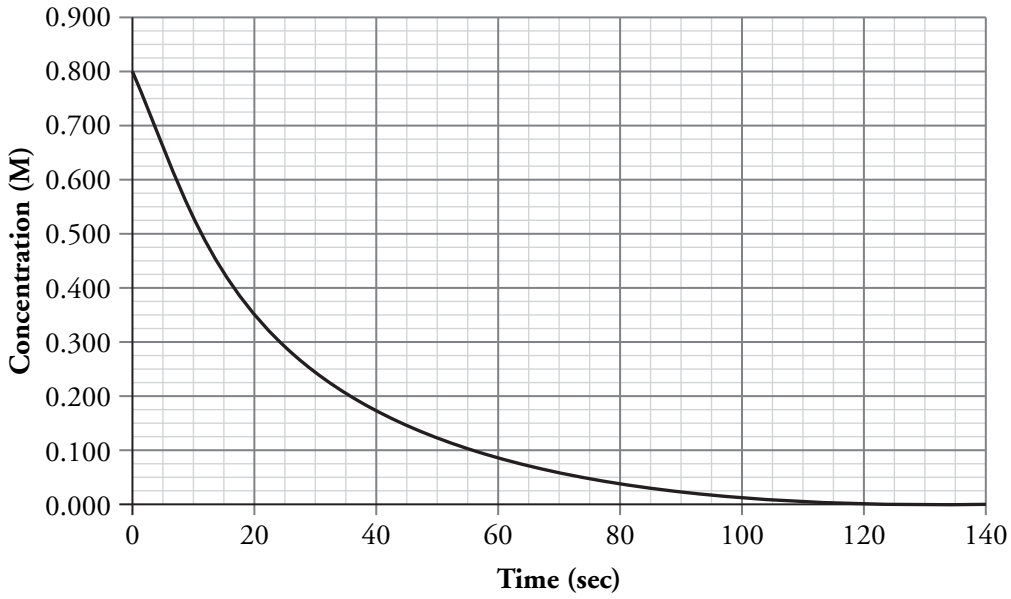
Rate of Reaction

How is the speed of a reaction measured?

Why?

Chemical reactions occur at different speeds. Some are almost instantaneous. Others require patience. For example, rust can form on iron in just a few days or over a period of months depending on the conditions. In order to study the factors that change the speed of a reaction, we must first develop an understanding of how the rate of reaction is monitored during a reaction.

Model 1 – Concentration versus Time Graph



1. The graph in Model 1 illustrates how the concentration of a species in a chemical reaction changes over time.

   a. What unit is the concentration measured in?

   b. What unit is the time measured in?

2. Consider the data in Model 1.

   a. What was the concentration of the species when the chemical reaction was initiated?

   b. Did the concentration of the species increase or decrease over time?

   c. Was the species a reactant or product in the reaction? Justify your reasoning.

3. Consider the data in Model 1.

   a. What was the change in the concentration of the species in Model 1 during the first 10 seconds of the reaction? Include units in your numeric answer.

   b. What was the change in the concentration of the species in Model 1 between the 60 and 70 second marks? Include units in your numeric answer.

   c. Was the rate of change for this species the same during these two time periods? Justify your reasoning. If no, in which time period is the rate of change faster?

Read This!

The rate of change for a species in a chemical reaction is usually defined as the change in its concentration over a specific unit of time.

$$\text{rate} = \frac{\Delta[\ ]}{\Delta t}$$

Depending on the conditions of the reaction, this rate could have the units of molarity per second, molarity per minute, molarity per hour, etc. Note that the rate of change for a chemical species, and for the reaction, is rarely constant. As reactants are used up, the rate often slows down. Although this leads to a curved graph, the average rate between two data points can be approximated using the slope of the graph between those points.

4. Use the data in Model 1 to calculate the average rate of change for the chemical species shown for the following time periods during the reaction. Be sure to include units in your calculation.

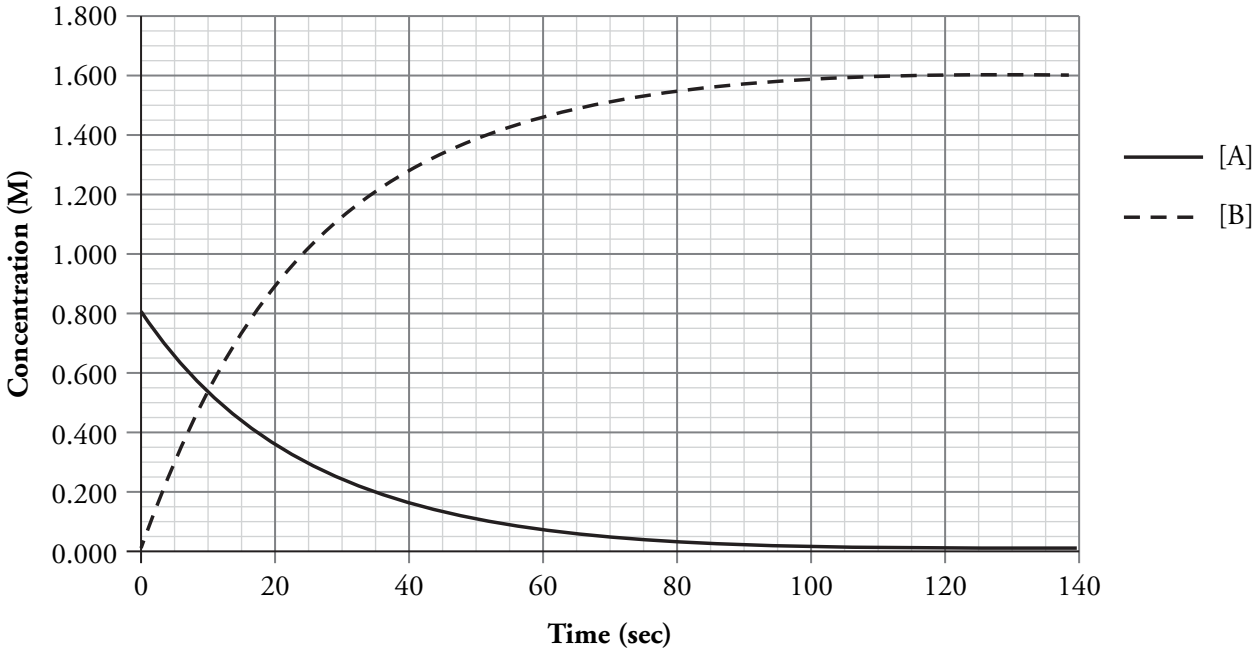
   a. The first 10 seconds.

   b. The time between 30 and 40 seconds.

   c. The time between 60 and 70 seconds.

5. The rates you calculated in Question 4 should be negative values. Why does it make sense that they are negative?

Model 2 – Two Species in the Reaction



6. The graph in Model 2 contains the same data as that in Model 1, but data about a second species in the reaction has been added to the graph.

   a. Which line in Model 2 is the same line as in Model 1, the solid or dashed line?

   b. Does the new data illustrate the change in concentration of a reactant or product of the reaction? Justify your reasoning.

7. Use the data in Model 2 to calculate the average rate of change for species B for the following time periods during the reaction. Be sure to include units and a sign (+ or –) on your calculation.

   a. The first 10 seconds.

   b. The time between 30 and 40 seconds.

   c. The time between 60 and 70 seconds.

8. Summarize the calculations you have performed in the previous questions in the table below.

	$\frac{\Delta[A]}{\Delta t}$	$\frac{\Delta[B]}{\Delta t}$
First 10 seconds		
Between 30 and 40 seconds		
Between 60 and 70 seconds		

9. Based on the information in the table in Question 8, which chemical reaction best describes the reaction that was studied for Model 2? Justify your reasoning.

I. $2A \rightarrow B$ II. $A \rightarrow 2B$ III. $A + B \rightarrow C$ IV. $A + 2B \rightarrow C$

Read This!

Depending on the mole ratios of the components of a chemical reaction, you could observe different rates of change for different species. How then can one numerical value for the rate of reaction be determined? By convention, the rate of a reaction is equal to the absolute value of the rate of change for any species that has a coefficient of one in the balanced reaction as written. Think of it as the time needed for the reaction to occur 6.022×10^{23} times.

10. Based on the data in Model 2, what is the initial rate of reaction for the chemical process that was investigated?

11. Consider the following reaction:

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

Experimental data indicate the initial rate of change for nitrogen is −0.060 M/s.

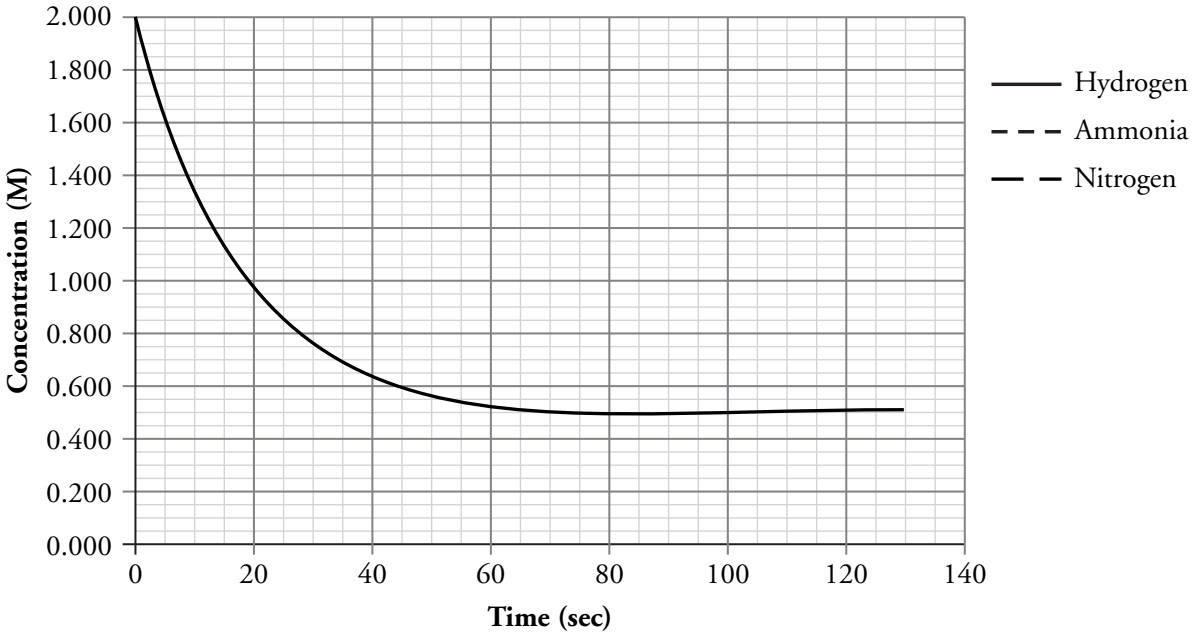
a. Calculate the initial rate of change for hydrogen.

b. Calculate the initial rate of change for ammonia.

c. Calculate the initial rate of reaction.

12. The graph below shows the rate of change for hydrogen in the following reaction. Sketch the rate curves for nitrogen and ammonia. The initial concentration of nitrogen is 0.500 M. There is no presence of ammonia initially.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$



Extension Questions

13. In order to gather the data required to produce the graphs in this activity, or any reaction rate graph, an experimenter must be able to quickly measure changes in concentration, either directly or indirectly, of at least one component of a chemical reaction. Match the following lab tools with the situation in which they might be used. If you are not familiar with the instruments below, use Internet or other resources to determine what the instruments measure.

A. pH meter	_____	Used to monitor a reaction that involves a colored reactant or product.
B. Manometer	_____	Used to monitor a reaction that involves a chiral (optically active) reactant or product.
C. Spectrophotomer	_____	Used to monitor a reaction that involves an acidic or basic reactant or product.
D. Thermometer	_____	Used to monitor a reaction that involves a gaseous reactant or product.
E. Optical rotation polarimeter	_____	Used to monitor a reaction that is exothermic or endothermic, with a known enthalpy.

14. Consider the following reaction:

$$N_2O_4(g) \rightarrow 2NO_2(g)$$

The rate of the reaction above can be studied at constant temperature using a pressure probe. However, the data are complicated due to the presence of two gases.

a. If the reaction vessel initially contained only dinitrogen tetroxide, would you expect an overall increase or decrease in pressure as the reaction proceeds? Justify your reasoning.

b. Suppose the above reaction showed an increase of 0.500 kPa in 10 seconds. What would be the change in pressure for dinitrogen tetroxide in the same time period?