Kinetics
5.3 Concentration Changes Over Time
Worksheet Key

1) The reaction between sucrose and water to produce fructose and glucose is first order overall. The data below shows the change in concentration of sucrose over time at 298 K.

$$C_{12}H_{22}O_{11}(aq) + H_2O(l) \rightleftharpoons C_6H_{12}O_6(aq)_{\text{fructose}} + C_6H_{12}O_6(aq)_{\text{glucose}}$$

$[C_{12}H_{22}O_{11}]$	Time (min)
1.002	0.0
0.808	60.0
0.630	130.0

a. Find the rate of disappearance of $C_{12}H_{22}O_{11}$ from t = 0 min to t = 60 min.

$$\text{Rate}_{C_{12}H_{22}O_{11}} = -\frac{\Delta[C_{12}H_{22}O_{11}]}{\Delta t} = -\frac{(0.808-1.002)M}{(60.0-0.00)\,\text{min}} = 3.23\times10^{-3}\,M/\text{min}$$

b. Find the rate of appearance of fructose from t = 0 min to t = 60 min.

The rate of appearance of fructose is also 3.23×10^{-3} *M*/min, as their mole ratio is 1:1 in the balanced chemical equation.

c. Calculate the rate constant for the decomposition of sucrose at 25°C. Include units.

$$\ln\left[C_{12}H_{22}O_{11}\right]_t - \ln\left[C_{12}H_{22}O_{11}\right]_o = -kt$$

$$k = -\frac{\ln\left[C_{12}H_{22}O_{11}\right]_t - \ln\left[C_{12}H_{22}O_{11}\right]_o}{t}$$

$$k = -\frac{\ln(0.808) - \ln(1.002)}{60.0\,\text{min}} = 3.59\times10^{-3}\,\text{min}^{-1}$$

d. How long will it take for the concentration of sucrose to drop from 1.002 to 0.212 *M*?

$$\ln\left[C_{12}H_{22}O_{11}\right]_t - \ln\left[C_{12}H_{22}O_{11}\right]_o = -kt$$

$$t = -\frac{\ln\left[C_{12}H_{22}O_{11}\right]_t - \ln\left[C_{12}H_{22}O_{11}\right]_o}{k}$$

$$t = -\frac{\ln(0.212) - \ln(1.002)}{3.59\times10^{-3}\,\text{min}^{-1}} = 4.33\times10^{2}\,\text{min}$$

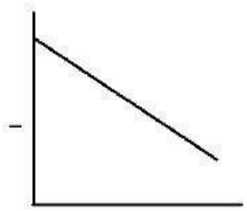
e. What is the half-life for the decomposition of sucrose at 25°C?

$$\ln[C_{12}H_{22}O_{11}]_t - \ln[C_{12}H_{22}O_{11}]_o = -kt$$
$$t = -\frac{\ln[C_{12}H_{22}O_{11}]_t - \ln[C_{12}H_{22}O_{11}]_o}{k}$$
$$t_{1/2} = -\frac{\ln(0.5) - \ln(1.0)}{3.59\times10^{-3}\text{ min}^{-1}} = 193\text{ min}$$

2) The decomposition of an unknown molecule, A, was found to be a first order process.

a. The graph below was compiled after data from an experiment involving the decomposition of this compound at 25°C was analyzed. Label the graph's vertical axis.

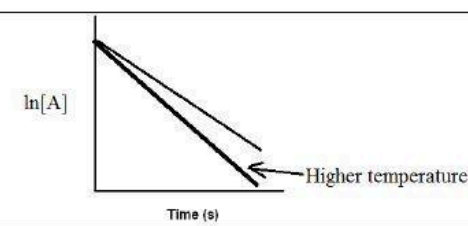
ln[A]



b. Write the units of the rate constant, k, for the decomposition of this unknown compound.

The unit for the rate constant is s^{-1}.

c. On the above graph, draw a line that shows the results that would be expected if the same experiment was repeated at a higher temperature.



3) A 1.0×10^2 mol sample of a compound that undergoes a first order process is known to have a half-life of 15 minutes. How many moles of the sample remain after 45 minutes?

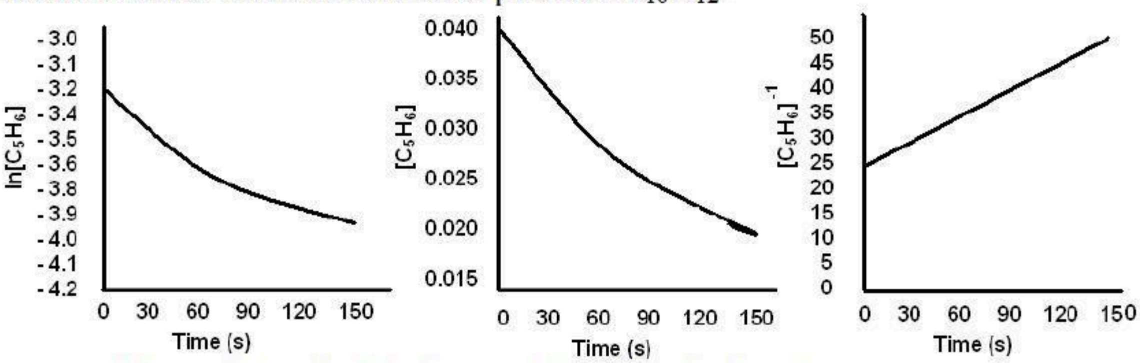
The sample goes through three half lives in 45 minutes.

$$\frac{1.0\times10^2\text{mol}}{2} = 5.0\times10\text{ mol},\ \frac{5.0\times10\text{ mol}}{2} = 25\text{ mol},\ \frac{25\text{ mol}}{2} = 13\text{ mol}$$

4) A gas with a partial pressure of 2.00 atm is placed in a ridged container. The gas decomposed through a first order process with a half-life of 20 minutes. How much time will it take for the partial pressure of that gas to drop to 0.25 atm?

0.25 x 2 =0.50; 0.50 x 2 = 1.0; 1.0 x 2 = 2.0 (The gas must go through 3 half lives.) 3 x 20min = 60 minutes. (60 minutes must pass.)

5) C_5H_6 reacts with itself to form $C_{10}H_{12}$ according to the following process. 2 $C_5H_6(aq) \rightarrow C_{10}H_{12}(aq)$. The three graphs below were constructed using data pertaining to changes in concentration of C_5H_6 over time at a set temperature. The data was collected during an experiment in which pure C_5H_6 was mixed with distilled water where it reacted to produce $C_{10}H_{12}$.



a. What is the order to the overall reaction? Justify your answer.

The reaction is second order, as the plot of $[C_5H_6]^{-1}$ vs. time is a straight line.

b. What is the rate law for the overall reaction?

Rate = $k[C_5H_6]^2$

c. Calculate the rate constant, k, for the reaction? (Include units) (Hint: Use the graphs to estimate numerical values.)

$$kt = \frac{1}{[C_5H_6]_t} - \frac{1}{[C_5H_6]_o}$$

$$k(150\text{s}) = \frac{1}{(0.020M)} - \frac{1}{(0.040M)} = 25M^{-1}$$

$$k = \frac{25M^{-1}}{150\text{s}} = 0.17M^{-1}\text{s}^{-1}$$

d. Calculate the concentration of C_5H_6 when 250 seconds have passed.

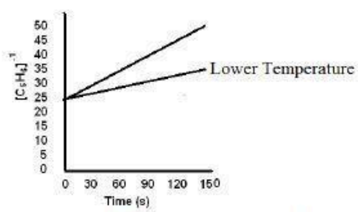
$$kt = \frac{1}{[C_5H_6]_t} - \frac{1}{[C_5H_6]_o}$$

$$\frac{1}{[C_5H_6]_t} = kt + \frac{1}{[C_5H_6]_o} = (0.17M^{-1}s^{-1})(250s) + \frac{1}{(0.040M)}$$

$$\frac{1}{[C_5H_6]_t} = 68M^{-1}$$

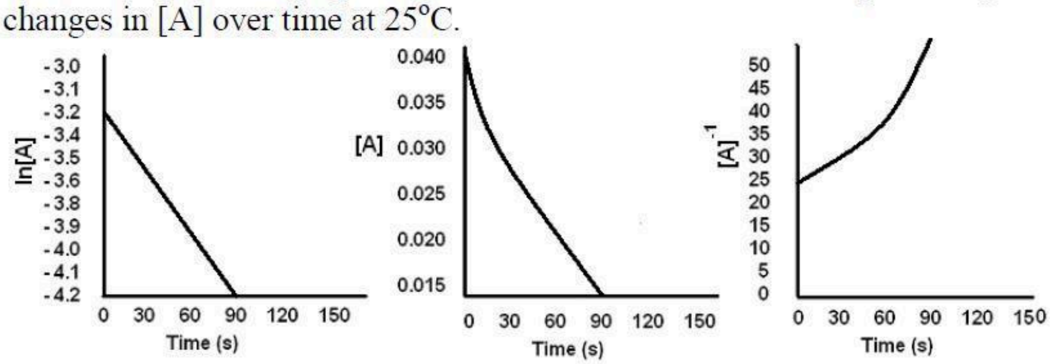
$$[C_5H_6]_t = \frac{1}{68} = 0.015M$$

e. On the plot of $[C_5H_6]^{-1}$ vs. time, draw a line that shows the results that would be expected if the same experiment was repeated at a lower temperature.



The line must start at the same point on the y-axis and must have a less steep slope.

6) An unknown compound decomposes according to the following process. A → 2 B The three graphs below were constructed with data pertaining to changes in [A] over time at 25°C.



a. What is the order of the overall reaction? Justify your answer.

The overall reaction is first order, as a plot of ln[A] vs. time produces a straight line.

b. What is the rate law for the overall reaction?

Rate = k[A]

c. Calculate the rate constant, k, for the reaction at 25°C? (Include units) (Hint: Use the graphs to estimate numerical values.)

$$\ln[A]_t - \ln[A]_o = -kt$$
$$k = -\frac{\ln[A]_t - \ln[A]_o}{t} = -\frac{(-4.2) - (-3.2)}{90\text{s}} = 1.1\times10^{-2}\,\text{s}^{-1}$$

d. What is the half life for the decomposition of 'A' at 25°C.

$$\ln[A]_t - \ln[A]_o = -kt$$
$$t = -\frac{\ln[A]_t - \ln[A]_o}{k}$$
$$t_{1/2} = -\frac{\ln(0.5) - \ln(1.0)}{1.1\times10^{-2}\,\text{s}^{-1}} = 63\text{ s}$$

e. Calculate [A] when 150 seconds have passed.

$$\ln[A]_t - \ln[A]_o = -kt$$
$$\ln[A]_t = -kt + \ln[A]_o$$
$$\ln[A]_t = -1.1\times10^{-2}\,\text{s}^{-1}(150\text{s}) + (-3.2)$$
$$[A]_t = e^{(-1.1\times10^{-2}\,\text{s}^{-1}(150\text{s})+(-3.2))}$$
$$[A]_t = 7.8\times10^{-3}\,M$$

7) Which of the following processes has the longer half-life? Justify your answer.

Process	Rate Law	Rate Constant
1	Rate = k[A][B]	$k = 6.79\ M^{-1}\text{min}^{-1}$
2	Rate = k[B][C]	$k = 14.55\ M^{-1}\text{min}^{-1}$

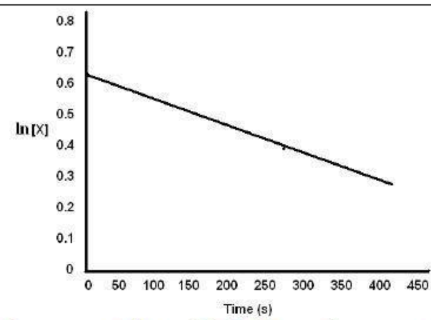
Process 1 has a longer half-life.

- Both processes are second order.
- Process 1 occurs at a slower rate when both systems share the same initial concentrations, as its rate constant has a smaller magnitude.
- The rate constant is inversely proportional to the half-life.

8) The following data was obtained for the chemical reaction: X → 2 Y + 2 Z.

[X]	Time (min)
1.881	0
1.766	78
1.499	280
1.339	420

a. Is the reaction zero order, first order or second order? (Hint: Make a graph)



The reaction is 1st order, as a plot of ln[X] vs. time produces a straight line.

b. What is the rate law for this reaction?

Rate = k[X]