

Chemistry 1020, Module 12A

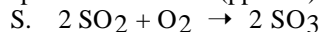
■ *What is Meant By "Rate of a Chemical Reaction"*

2a) What does a chemist mean by "rate of a reaction"? (p. 557)

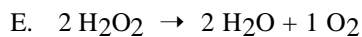
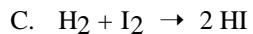
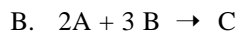
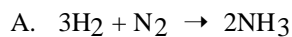
b) On the axes below draw two sketches, one showing how the concentration of a reactant changes with time and the other showing how the concentration of a product changes with time as a chemical reaction proceeds. (p. 558)



c) Write all of the possible mathematical expressions which might be used to represent "reaction rate" for the specified reaction. (pp. 560)

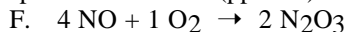


$$-\frac{(\text{SO}_2)}{\text{time}} \quad \text{or} \quad -\frac{(\text{O}_2)}{\text{time}} \quad \text{or} \quad \frac{(\text{SO}_3)}{\text{time}}$$



■What is Meant By "Rate of a Chemical Reaction" (continued)

2c) Write all of the possible mathematical expressions which might be used to represent "reaction rate" for the specified reaction. (pp. 560)

**✓✓✓■Relating the Various Ways of Writing Reaction Rate**

3a) Given the balanced equation $1 A + 2 B \rightarrow 1 C + 3 D$, write all of the possible mathematical expressions which might be used to represent "reaction rate". (pp. 560)

b) If the rate of change of one of the substances in a is known, what mathematical equation(s) could be used to obtain the rates of change of the other substances? (p. 560)

c) State the equation in b in words.

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✓✓✓■ *Relating the Various Ways of Writing Reaction Rate (continued)*

3d) Use the given rate of reaction to calculate the rate at which the other reactant(s) and products(s) disappear and appear for each of the following reactions. Show all of your work.

S. Eqn:	2 H ₂	+	1 O ₂	→	2 H ₂ O	
Math Expression for rate	$-\frac{(H_2)}{t}$		$-\frac{(O_2)}{t}$		$\frac{(H_2O)}{t}$	
Rate of appearance or Disappearance	1.4*10 ⁻² M/sec		$\frac{- (H_2)}{2} = \frac{- (O_2)}{1}$ $\frac{1.4*10^{-2}}{2} = \frac{x}{1}$ 2x = 1.4*10 ⁻² M/sec x = 0.70*10 ⁻² M/sec		$\frac{- (H_2)}{2} = \frac{(H_2O)}{2}$ $\frac{1.4*10^{-2}}{2} = \frac{x}{2}$ x = 1.4*10 ⁻² M/sec	
A. Eqn:	3 H ₂	+	1 N ₂	→	2 NH ₃	
Math Expression for rate						
Rate of appearance or Disappearance					2.5*10 ⁻³ M/sec	
B. Eqn:	2 SO ₂	+	1 O ₂	→	2 SO ₃	
Math Expression for rate						
Rate of appearance or Disappearance			1.2*10 ⁻¹ M/sec			

✓✓✓■ *Relating the Various Ways of Writing Reaction Rate (continued)*

3d) Use the given rate of reaction to calculate the rate at which the other reactant(s) and products(s) disappear and appear for each of the following reactions. Show all of your work.

C. Eqn:	2N_2	+	3O_2	→	$2 \text{N}_2\text{O}_3$	
Math Expression for rate						
Rate of appearance or Disappearance	$8.9 \times 10^{-2} \text{ M/sec}$					
D. Eqn:	4Na	+	1O_2	→	$2 \text{Na}_2\text{O}$	
Math Expression for rate						
Rate of appearance or Disappearance			$1.2 \times 10^4 \text{ M/sec}$			
E. Eqn:	2CO	+	1O_2	→	2CO_2	
Math Expression for rate						
Rate of appearance or Disappearance					$4.2 \times 10^{-5} \text{ M/sec}$	

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✓✓✓■ *Relating the Various Ways of Writing Reaction Rate (continued)*

3d) Use the given rate of reaction to calculate the rate at which the other reactant(s) and products(s) disappear and appear for each of the following reactions. Show all of your work.

F. Eqn:	2 S	+	3 O ₂	→	2 SO ₃	
Math Expression for rate						
Rate of appearance or Disappearance			3.4*10 ⁻³ M/sec			

✓✓✓■ **Determining the Instantaneous Rate of a Reaction From Experimental Data**

4. In the previous questions, you learned the different things which “rate of reaction” could mean. Once you decide which is of interest to you (or, more likely, which is easiest to measure), this Learning Goal shows how to calculate a value for the rate. That is, it shows how the given rates in the problem #3 above might be calculated. *To calculate a value for the rate of a reaction, you...*

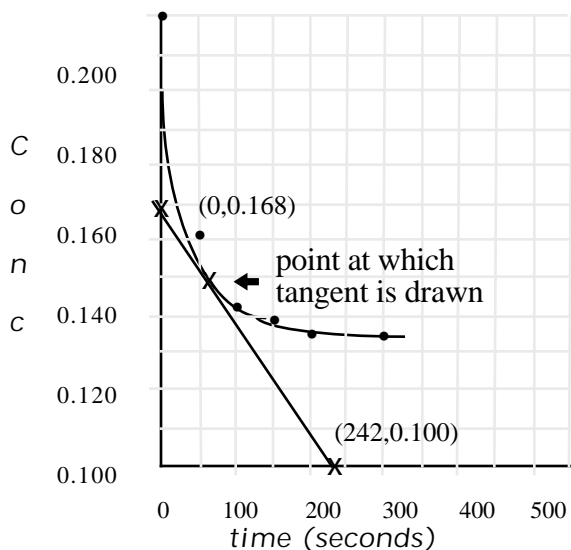
- Decide which reactant or product you are going to follow (measure).
- Measure the concentration of that substance at different times as the reaction proceeds.
- Plot the data.
- Draw a smooth curve through the data. (Note “curve” because the data probably won’t be a straight line.)
- Draw a straight line tangent to the curve at the point in time at which you want to calculate the rate.
- Choose two widely-spaced points on the tangent line.
- Use the coordinates of the points to calculate the slope using $\Delta y/\Delta x$ in the usual fashion.

Use the indicated plot to determine the rate of the reaction at the indicated time. Show all work.

S. Reaction: $2 A + 1 B \rightarrow 3 C$

Variation of time with concentration:

Time (sec)	(B)
0	0.200
50	0.161
100	0.142
150	0.138
200	0.135
300	0.134



What is the reaction rate at 75 seconds?

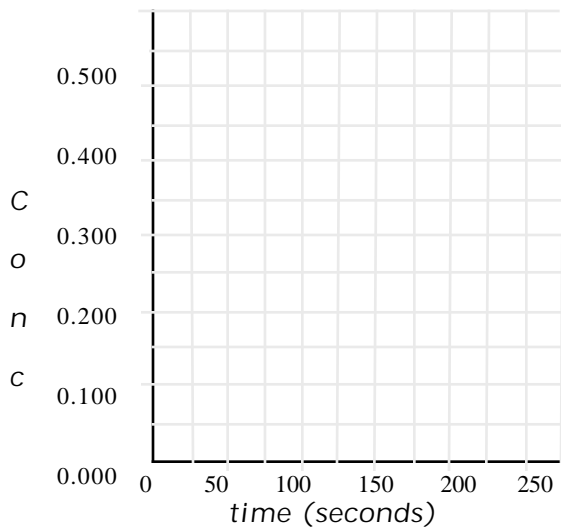
$$\text{slope} = \frac{y}{x} = \frac{0.168 - 0.100}{0 - 242} = -2.81 \cdot 10^{-4}$$

$$\text{Therefore, rate} = -\frac{(B)}{t} = -(-2.81 \cdot 10^{-4} \frac{M}{\text{sec}}) = 2.81 \cdot 10^{-4} \frac{M}{\text{sec}}$$

A. Reaction: $1 A + 2 B \rightarrow 1 C$

Variation of time with concentration:

Time (sec)	(C)
0	0.000
25	0.231
50	0.350
75	0.404
100	0.436
125	0.449



What is the reaction rate at 110 seconds?

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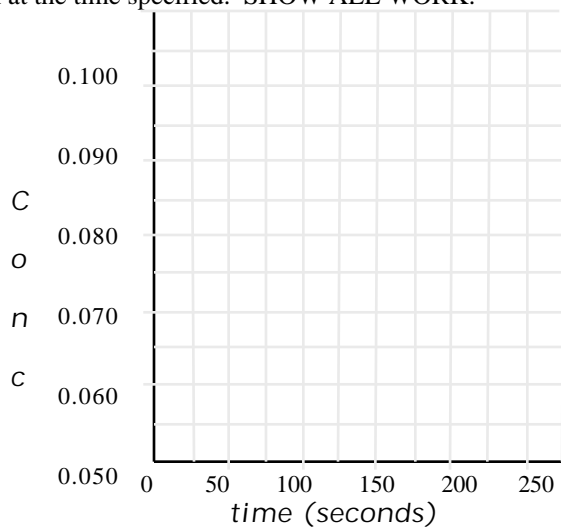
✓✓✓■ **Determining the Instantaneous Rate of a Reaction From Experimental Data (continued)**

4. Determine the reaction rate of the given equation at the time specified. SHOW ALL WORK.

B. Reaction: $2 A + 1 B \rightarrow 3 C$

Variation of time with concentration:

Time (sec)	(B)
0	0.100
25	0.080
50	0.071
75	0.069
100	0.067
150	0.066

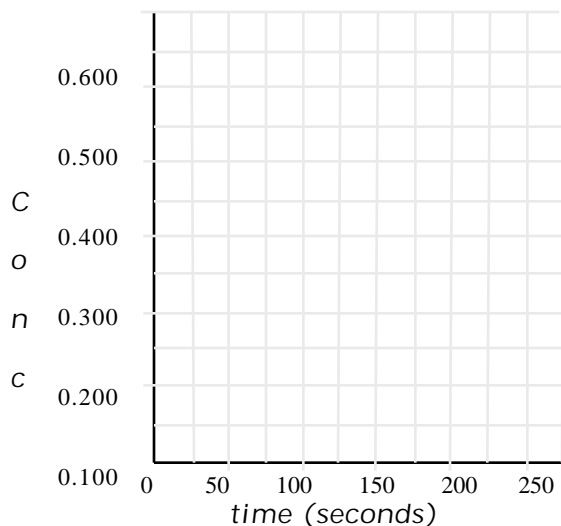


What is the reaction rate at 36 seconds?

C. Reaction: $2 A + 2 B \rightarrow 1 C$

Variation of time with concentration:

Time (sec)	(C)
0	0.100
50	0.195
100	0.293
150	0.342
200	0.366
250	0.376



What is the reaction rate at 175 seconds?

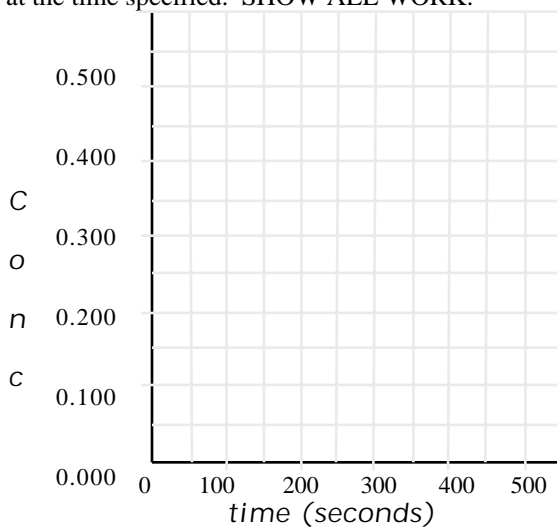
✓✓✓■ **Determining the Instantaneous Rate of a Reaction From Experimental Data (continued)**

4. Determine the reaction rate of the given equation at the time specified. SHOW ALL WORK.

D. Reaction: $2 A + 3 B \rightarrow 1 C$

Variation of time with concentration:

Time (sec)	(C)
0	0.000
50	0.201
100	0.302
200	0.377
300	0.396
400	0.402

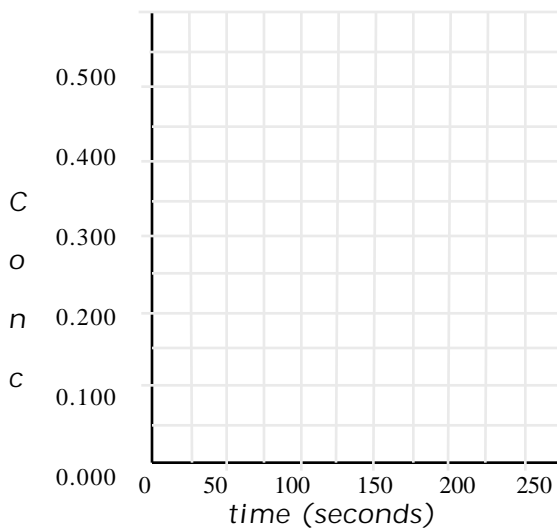


What is the reaction rate at 150 seconds?

E. Reaction: $2 A + 1 B \rightarrow 3 C$

Variation of time with concentration:

Time (sec)	(A)
0	0.446
50	0.222
100	0.110
150	0.062
200	0.031
250	0.016



What is the reaction rate at 150 seconds?

■ **Variation of Rate With Concentration Change: Rate Law, Rate Constant, and Order of a Reaction**

5a) Now that you know what “rate of a reaction” means and you know how to calculate a value for the rate as indicated in #4 above, it is time to talk of the equation which shows how the rate of the reaction is related to the concentrations of the reactants in the reaction. This equation is called a “rate law” or “rate expression.”

Define rate law (p. 561)

b) Write the rate law for the balanced equation $a A + b B \rightarrow c C + d D$ and label the rate constant and the order with respect to each reactant. (p. 561) (Note: The symbol for rate constant is a lower case "k". When writing by hand, it is usually better to use a script "k" for the rate constant to prevent confusion with a capital "K" which is used by chemist to indicate equilibrium constant.)

c) Define rate constant. (p. 561)

d) Define reaction order. (p. 561)

e) Write a rate expression for substance (X) reacting by the indicated order.

-zero order

-first order

-second order

-third order

f) What is the relationship between the stoichiometry of a reaction (i.e. the coefficients in the balanced equation) and its rate law (or the order of the reactants in the reaction)? (There is NO relationship!! The two are totally independent!!)

✓✓✓■ **Variation of Rate With Concentration Change: Detailed Consideration of Reaction Order**

6a) Write the rate expression for the specified reaction.

S. $N_2 + 3 H_2 \rightarrow 2 NH_3$. The reaction is first order with respect to hydrogen and second-order with respect to nitrogen.

$$\text{rate} = k(N_2)^2(H_2)^1 \quad (\text{When working problems remember to write "k" in script.})$$

A. $2A + B \rightarrow 3 C$. The reaction is first order with respect to both reactants.

B. $2 H_2 + O_2 \rightarrow 2 H_2O$. The reaction is zero order with respect to hydrogen and second order with respect to oxygen.

C. $3 M + N \rightarrow 4 P$. The reaction is first order with respect to M and zero order with respect to N.

D. $C + 2 D \rightarrow E$. The reaction is second order with respect to C and first order with respect to D.

✓✓✓■ **Variation of Rate With Concentration Change: Detailed Consideration of Reaction Order (continued)**

6a) Write the rate expression for the specified reaction.

E. $3 X + 2 Y \rightarrow 2 Z$. The reaction is zero order with respect to X and first order with respect to Y.

b) Complete the following tables to indicate how reaction rate changes as concentration of a reactant varies for each order of reaction.

Concentration of (A)	Rate if reaction is			
	Zero Order (rate= $k(A)^0$)	First Order (rate= $k(A)^1$)	Second Order (rate= $k(A)^2$)	Third Order (rate= $k(A)^3$)
0.01	0.23 M/sec	0.37 M/sec	0.45 M/sec	0.69 M/sec
0.02				
0.06				
0.05				
0.20				

c) Summarize the data from the table above by indicating below the relationship between change in concentration and change in rate of the reaction?

Order of reaction in X *What happens to rate as (X) changes*

•Zero order in (X)

•First order in (X)

•Second order in (X)

•Third order in (X)

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✓✓✓■ Determination of Rate Law from Experimental Data

7/8) Work each of the following using the experimental data given. Be sure to explain all reasoning. (Section 12.3)

S.	Rate (M/sec)	(HBr)	(O ₂)
Experiment 1:	5.4×10^{-3}	0.15	0.98
Experiment 2:	10.8×10^{-3}	0.30	0.98
Experiment 3:	2.2×10^{-2}	0.30	1.96

- a) What is the order of the reaction with respect to each of the reactants?
 Use experiments 1 & 2 where (O₂) is constant to obtain the order with respect to (HBr). In going from 1 to 2, we see that rate doubles as (HBr) doubles. Therefore, order in (HBr) = 1.

Use experiments 2 & 3 where (HBr) is constant to obtain the order with respect to (O₂). In going from 2 to 3, we see that rate doubles as (O₂) doubles. Therefore, order in (O₂) = 1 also

- b) What is the overall order of the reaction?
 Overall order = sum of the orders of the reactants = 1 + 1 = 2

- c) What is the value of the rate constant? Ignore its units.
 rate expression is: $\text{rate} = k(\text{HBr})^1(\text{O}_2)^1$

Solve for k to get: $k = \frac{\text{rate}}{(\text{HBr})^1(\text{O}_2)^1} = \frac{5.4 \times 10^{-3}}{0.15 \times 0.98} = 3.7 \times 10^{-2}$

Note: We used the data from experiment 1 to get obtain k. You could also use that from 2 or 3.

- d) What is the overall rate law for the reaction?

$$\text{rate} = 3.7 \times 10^{-2}(\text{HBr})^1(\text{O}_2)^1$$

A.	Rate (M/sec)	(A)	(B)
Experiment 1:	6.4×10^{-2}	0.10	0.20
Experiment 2:	6.4×10^{-2}	0.10	0.40
Experiment 3:	1.28×10^{-1}	0.20	0.20

- a) What is the order of the reaction with respect to each of the reactants?

- b) What is the overall order of the reaction?

- c) What is the value of the rate constant? Ignore its units.

- d) What is the overall rate law for the reaction?

✓✓✓■ **Determination of Rate Law from Experimental Data (continued)**

7/8) Work each of the following using the experimental data given. Be sure to explain all reasoning.

B.	Rate (M/sec)	(HBr)	(NO ₂)
Experiment 1:	1.20×10^{-4}	0.10	0.50
Experiment 2:	2.40×10^{-4}	0.20	0.50
Experiment 3:	6.48×10^{-3}	0.20	1.50

- a) What is the order of the reaction with respect to each of the reactants?
- b) What is the overall order of the reaction?
- c) What is the value of the rate constant? Ignore its units.
- d) What is the overall rate law for the reaction?

C.	Rate (M/sec)	(M)	(N)
Experiment 1:	1.5×10^{-2}	0.10	0.20
Experiment 2:	4.5×10^{-2}	0.10	0.60
Experiment 3:	4.5×10^{-2}	0.50	0.60

- a) What is the order of the reaction with respect to each of the reactants?
- b) What is the overall order of the reaction?
- c) What is the value of the rate constant? Ignore its units.
- d) What is the overall rate law for the reaction?
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✓✓✓■ *Determination of Rate Law from Experimental Data (continued)*

7/8) Work each of the following using the experimental data given. Be sure to explain all reasoning.

D.	<u>Rate (M/sec)</u>	<u>(X)</u>	<u>(Y)</u>
Experiment 1:	2.10×10^{-3}	0.10	0.20
Experiment 2:	0.26×10^{-3}	0.050	0.20
Experiment 3:	0.13×10^{-3}	0.050	0.10

- What is the order of the reaction with respect to each of the reactants?
- What is the overall order of the reaction?
- What is the value of the rate constant? Ignore its units.
- What is the overall rate law for the reaction?

E.	<u>Rate (M/sec)</u>	<u>(NO)</u>	<u>(Cl₂)</u>
Experiment 1:	4.2×10^{-3}	0.20	0.30
Experiment 2:	1.4×10^{-3}	0.050	0.10
Experiment 3:	1.4×10^{-3}	0.20	0.10

- What is the order of the reaction with respect to each of the reactants?
 - What is the overall order of the reaction?
 - What is the value of the rate constant? Ignore its units.
 - What is the overall rate law for the reaction?
-

✓✓✓■ Determination of Rate Law from Experimental Data (continued)

7/8) Work each of the following using the experimental data given. Be sure to explain all reasoning.

F.	Rate (M/sec)	(X)	(Y)
Experiment 1:	6.00×10^{-2}	0.15	0.60
Experiment 2:	1.50×10^{-2}	0.15	0.30
Experiment 3:	6.67×10^{-3}	0.050	0.60

- a) What is the order of the reaction with respect to each of the reactants?
- b) What is the overall order of the reaction?
- c) What is the value of the rate constant? Ignore its units.
- d) What is the overall rate law for the reaction?

✓✓✓■ Half-Life Problems when Time Elapsed Is An Integer Multiple of the Half-Life

9a) Define half-life. (p. 570)

- b) What can be said about the value of the half-life for a first-order reaction? (I t is a constant.)

- c) S. The half-life for the 1st order reaction, $A \rightarrow 2 B$, is 2 weeks. If one has 200.0 grams at the beginning of an experiment, how many grams will remain after 10 weeks?

Can solve this problem simply because time elapsed (10 weeks) is 5 times the half-life as follows:

200 g → 100 g → 50 g → 25 g → 12.5 g → 6.25 g

0 weeks → 2 weeks → 4 weeks → 6 weeks → 8 weeks → 10 weeks

- A. The reaction, $2 C \rightarrow D$, is 1st order and its half-life is 10 minutes. If one starts with 40.0 grams of C at the beginning of an experiment, how many grams will be left after one hour?

- B. The half-life for the 1st order reaction, $M \rightarrow 2 N$, is 40 minutes. If one has 300.0 grams of M after the reaction has been occurring for 2 hours, how much was present at the beginning?

✓✓✓■ *Half-Life Problems when Time Elapsed Is An Integer Multiple of the Half-Life*

9c) C. The half-life of the 1st order reaction, $3 R \rightarrow 2 P$, is 15 seconds. If one has 500.0 grams of R at time zero, **how much decays in 1 minute?**

D. The half-life of the 1st order reaction, $2A \rightarrow B$, is 2.5 years. If one has 10.0 grams of A in 1980 how much remains in 1990?

E. The half-life of the 1st order reaction, $A \rightarrow X$, is 1.5 years. If one has 44.0 grams of A left after 6 years has passed, how much A was present at the beginning?

F. The half-life of the 1st order reaction, $A \rightarrow B$, is 14 minutes. If one has 16 grams of A now, how much would remain after 6 half-lives have passed if the substance reacts in this manner?

✓✓✓■ *Half-Life Problems when Time Elapsed Is NOT An Integer Multiple of the Half-Life*

10a) Write the rate law and the integrated rate law for reaction which is first order in (X). (p. 568)

•rate law:

•integrated rate law:

b) What is the equation relating half-life of a first order reaction and its rate constant? (p. 572)

c) State the relationship between half-life of a first order reaction and its rate constant in words. (p. 572)

✓✓✓■ **Half-Life Problems when Time Elapsed Is NOT An Integer Multiple of the $t_{1/2}$ (continued)**

10d) Work the indicated half-life problem using the integrated form of the rate law. (pp. 572)

- S. A certain reaction is found to undergo first-order decay with a half-life of 2.3 seconds. If there is 14 grams of the substance at the beginning of an experiment, how much will remain after 15 seconds?
 Cannot use simple method above because 15 is not an integer multiple of 2.3. I nstead, must use

$$\ln\left(\frac{X_0}{X}\right) = k \cdot t, \text{ where } k = \frac{0.693}{t_{1/2}}$$

$$\text{Therefore, } \ln\left(\frac{14 \text{ g}}{X}\right) = 0.301 \text{ sec}^{-1} \cdot 15 \text{ secs} \\ = 4.52$$

For this problem, $X_0 = 14 \text{ g}$, $t = 15 \text{ seconds}$,
 and $t_{1/2} = 2.3 \text{ seconds}$

$$\text{So } k = \frac{0.693}{2.3 \text{ seconds}} = 0.301 \text{ sec}^{-1}$$

$$\frac{14 \text{ g}}{X} = e^{4.52} = 91.8$$

$$\text{*Use a script letter "k" for "k" in problems below} \quad X = 14 \text{ g}/91.8 = 0.15 \text{ g remaining}$$

- A. A certain reaction is found to undergo first-order decay with a half-life of 14 hours. If you begin an experiment with 93 grams of the substance, how much would remain after three complete days?

- B. The half-life for a certain first-order reaction is found to be 9.2 minutes. If there is 1.2 grams of the substance remaining after 15 minutes, how much of the substance was present at the beginning?

- C. The half-life for a certain first-order reaction is found to be 1.2 hours. If there is 112 grams of the substance at the beginning of an experiment, how much will remain after 10 hours?

- D. The half-life for a certain first-order reaction is found to be 62 seconds. If there is 3.6 grams of the substance after 5 minutes, how much of the substance was present at the beginning?

- E. If 16 grams of a substance which reacts by a first-order reaction with a half-life of 82 minutes is allowed to react for 2 hours and 15 minutes, how much of the substance remains?

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■Bonding/Model Activity to Improve Ability to Visualize in 3-D

A. a) Draw the Lewis structure of acetic acid.

B. a) Draw the Lewis structure of CH_3COCH_3 (acetone).

C. a) Draw the Lewis structure of $\text{CH}_3\text{CH}_2\text{CH}_3$ (propane).

D. a) Draw the Lewis structure of CH_3Br (methyl bromide).

A-D b) Then use your model set to assemble a model of the species.

■ **Challenge Questions**

- A. From the experimental data below, determine the order of substance A for the reaction, $2 A \rightarrow B + C$.

Rate	(A)
0.0023 M/sec	0.0020 M
0.0053 M/sec	0.0035 M

- B. From the experimental data below, determine the order of substance A for the reaction, $1 A \rightarrow 2 B$.

Rate	(A)
0.0033 M/sec	0.0025 M
0.0058 M/sec	0.0035 M

- C. From the experimental data below, determine the order of substance A for the reaction, $2 X \rightarrow 2 Y + Z$.

Rate	(A)
0.0045 M/sec	0.0010 M
0.0073 M/sec	0.0025 M

- D. From the experimental data below, determine the order of substance A for the reaction, $1 X \rightarrow 2 Y$.

Rate	(A)
0.0043 M/sec	0.0017 M
0.0063 M/sec	0.0028 M

- E. From the experimental data below, determine the order of substance A for the reaction, $1 X \rightarrow 2 Y$.

Rate	(A)
0.0023 M/sec	0.0018 M
0.0063 M/sec	0.0027 M

- F. From the experimental data below, determine the order of substance A for the reaction, $1 X \rightarrow 2 Y$.

Rate	(A)
0.0012 M/sec	0.0013 M
0.0051 M/sec	0.0032 M

Special Note: See Sample Exercise 12.1 on page 560-1 for a sample similar to the challenge questions above.

Some properties of logarithms you may need to work these challenge problems:

$$\bullet \log (a \cdot b) = \log a + \log b$$

$$\bullet \log \frac{a^x}{b^x} = \log \left(\frac{a}{b} \right)^x$$

$$\bullet \log a^x = x \log a$$

$$\bullet \log \left(\frac{b}{a} \right) = - \log \left(\frac{a}{b} \right)$$

