Calculating Reaction Rates 1:

1. A 5.0g sample of magnesium reacts complete with a hydrochloric acid solution after 150 s. Express the average rate of consumption of magnesium, in units of g/min.
2. How long will it take to completely react 45.0g of $CaCO_{3(s)}$ with dilute HCl(aq) if the reaction proceeds at an average rate of 2.35g $CaCO_{3(s)}$/min under a given set of conditions?
3. The electrolysis of water produces oxygen gas at the rate of 32.5 ml/min in a certain experiment. What volume of oxygen gas can be produced in 7.50 min?
4. Which of the following are acceptable units for expressing reaction rate?
    a. Moles/sec
    b. Minutes/metre
    c. (Moles/litre)/second
    d. grams/litre
    e. mililitres/hour
    f. grams/min
5. Hydrogen and oxygen gas react in a fuel cell to produce water according to the equation:
6. $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O(l)$
    a. If the rate of water *production* is 1.34 mol/min, what is the rate of oxygen gas *consumption* expressed in mol/min?
7. Given that the concentration of $NO_{2(g)}$ is $0.40\ mol/L$ at $45\ s$ and $0.85\ mol/L$ at $80\ s$, what is the rate of production of $NO_2(g)$ in: $NO_2(g) + CO \rightarrow NO(g) + CO_{2(g)}$?

8. Which expression represents the rate for the product formation for the reaction:
$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$?

    a. $\text{rate} = \frac{\triangle[Mg]}{\triangle t}$

    b. $\text{rate} = \frac{\triangle[HCl]}{\triangle t}$

    c. $\text{rate} = \frac{\triangle[MgCl_2]}{\triangle t}$

    c. All of these are accurate representations of the rate.

9. Which statement represents a rate?
    a. The speed of a car is 50km/h.
    b. Half the product is produced.
    c. A family consumes 5L of milk.
    d. I ran for 45minutes

10. Which statement about the instantaneous rate of a reaction is correct?
    a. The higher the rate, the smaller the slope of a line on a concentration-time graph.
    b. The instantaneous rate is the slope of the tangent to a line on a concentration-time graph.
    c. The instantaneous rate is the slope of the cosine to a line on a concentration-time graph.
    d. All of these statements are correct.

11. What is the rate of production of NO gas if the concentration decreases from $0.32\ mol/L$ at $56\ s$ and $0.94\ mol/L$ at $78\ s$ for the reaction ?
    a. $-35\ mol/L \cdot s$
    b. $-2.8 \times 10^2\ mol/L \cdot s$
    c. $2.8 \times 10^{-2}\ mol/L \cdot s$
    d. $35\ mol/L \cdot s$

12. It takes $15\ minutes$ for the concentration of a reactant to decrease from $0.45\ mol/L$ to $0.030\ mol/L$. What is the rate of reaction in $mol/L \cdot s$?

13. According to the reaction A → B, the following data was collected: (right)

Time (s)	Concentration of B (mol/L)
0.0	0.0
10.0	0.30
20.0	0.50
30.0	0.60
40.0	0.65
50.0	0.67

    a) What is the average rate over the entire 50 seconds?
    b) What is the average rate for the interval 20 s to 40 s?

14. For the reaction A → products, the following data was collected: (below)

Time (min)	Mass of A (g)
0.0	25.0
1.0	20.0
2.0	17.0
3.0	15.0
4.0	13.0
5.0	12.0

    a) What is the average rate, in g A/min, over the entire 5 minutes?
    b) What is the average rate for the interval between 2.0 and 4.0 minutes?

    a) What is the average rate, in g A/min, over the entire 5 minutes?
    b) What is the average rate for the interval between 2.0 and 4.0 minutes?

15. The decomposition of acetaldehyde to methane and carbon dioxide occurs according to the following equation:

$$CH_3CHO(g) \rightarrow CH_4(g) + CO(g)$$

The results of an experiment are given below: (right)

a) What is the rate of decomposition of acetaldegyde between 42 s and 105 s?
b) What is the rate of decomposition in the interval 190 s to 480 s?

Time (s)	$[CH_3CHO]$ (mol/L)
42	0.00667
73	0.00626
105	0.00586
190	0.00505
242	0.00464
310	0.00423
384	0.00383
480	0.00342
665	0.00282
840	0.00241

3. Below is the data from an experiment that studied the following reaction: (below)

$2\ HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_{2(g)}$

HCl was placed in a beaker and massed immediately after adding $CaCO_3$ chips (time = 0). The mass of the beaker was recorded at 1.0 minute intervals for a total of 15 min. We will assume the loss of mass is the amount of carbon dioxide gas that escapes from the beaker.

Time (min)	**Mass of beaker and contents (g)**	**Mass loss (CO_2 produced) (g)**
0.0	200.00	
1.0	199.40	
2.0	199.00	
3.0	198.65	
4.0	198.35	
5.0	198.10	
6.0	197.90	
7.0	197.75	
8.0	197.65	
9.0	197.57	
10.0	197.52	

a) Complete the table.

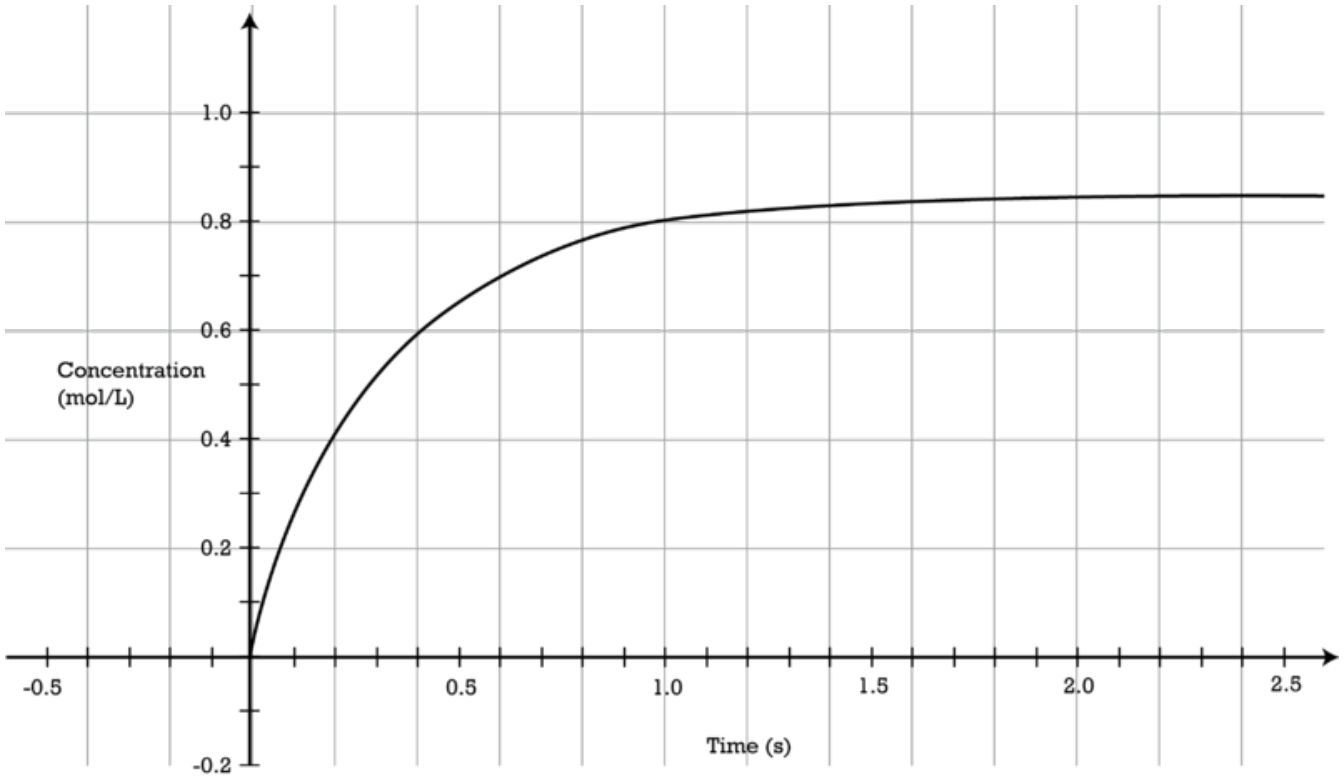
b) Determine the average rate, in g of CO_2/min, over the entire 10 minutes.

c) Determine the average rate for the intervals:

i) First 3 minutes.
ii) Last 3 minutes.

Instantaneous Rate Worksheet

1. For the graph below, draw a tangent line at $t = 0.40\ \text{s}$ and calculate the instantaneous rate.



2. The formation of nitrogen dioxide from nitrogen dioxide and oxygen gas was studied. The balanced equation for the reaction is:

$$O_2(g) + 2\ NO(g) \rightarrow 2\ NO_2\ (g)$$

The chemist measured the concentration of the three gases at various time intervals. The data is in the table below. Construct a well labeled graph (labeled axis with units, a title, etc.) to represent this data. Along the y-axis plot gas concentration and time on the x-axis.

Time (min)	**Concentration (mol/L)**		
	O_2	**NO**	**NO_2**
0.0	0.000343	0.000514	0.000000
2.0	0.000317	0.000461	0.000053
4.0	0.000289	0.000406	0.000108
6.0	0.000271	0.000368	0.000146
10.0	0.000242	0.000311	0.000204
16.0	0.000216	0.000259	0.000256
26.0	0.000189	0.000206	0.000308
41.0	0.000167	0.000162	0.000353
51.0	0.000158	0.000143	0.000372
61.0	0.000150	0.000127	0.000387
71.0	0.000144	0.000116	0.000399

Answer the following questions.

1. What is the average rate of consumption of nitrogen oxide and oxygen over the entire 71 minute interval? Determine the average rate for each.

2. What is the average rate of formation of nitrogen dioxide over the entire 71 minute interval?

3. What is the average rate of the consumption of NO and O_2 and the production of NO_2 each,

a) over the first 10 minutes
b)over the last 10 minutes?

4. Find the initial rates of consumption of O_2 and NO and the initial rate of formation of NO_2 as well as the rates at 4 minutes and 41 minutes into the experiment.

Reaction rate with stoichiometry worksheet

1. If NOCl(g) is decomposing at a rate of 1.1×10^{-8} mol/L/min in the following reaction:

$$2\ NOCl(g) \rightarrow 2\ NO(g) + Cl_2(g)$$

a) What is the rate of formation of NO(g)?
b) What is the rate of formation of $Cl_2(g)$?

2. Thiosufate ion is oxidized by iodine according to the following reaction:

$$2\ S_2O_3^{2-}(aq) + I_2\ (aq) \rightarrow S_4O_6^{2-}\ (aq) + 2\ I^-(aq)$$

If, in a certain experiment, 0.0080 mol of $S_2O_3^{2-}$ is consumed in 1.0 L of solution each second, What is the rate of consumption of I_2? At what rates are $S_4O_6^{2-}$ and I^- produced in this solution?

3. If the decomposition of N_2O_5 gas occurs at a rate of 0.20 $molL^{-1}s^{-1}$, what would be the rate of formation of NO_2 gas and O_2 gas if the equation for the reaction is

$$2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$$

4. If ammonia gas, NH_3, reacts at a rate of 0.090 mol/Ls according to the reaction

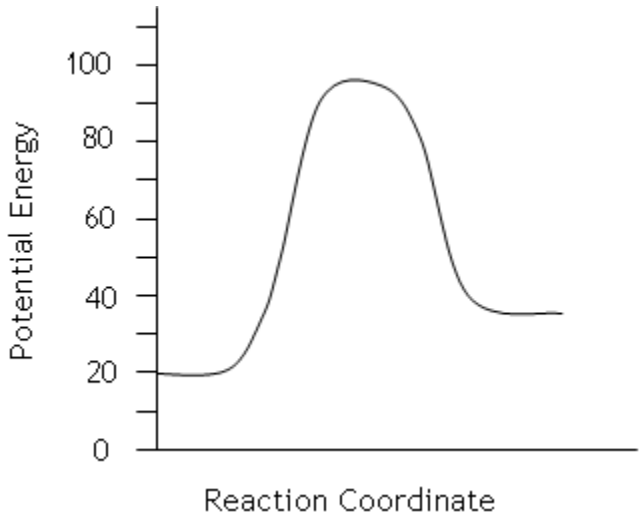
$$4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$$

a) at what rate does oxygen gas react under the same conditions?
b) what is the rate of formation of water?
c) what is the rate of production of nitrogen monoxide?

Collision Theory and Potential Energy diagrams worksheet

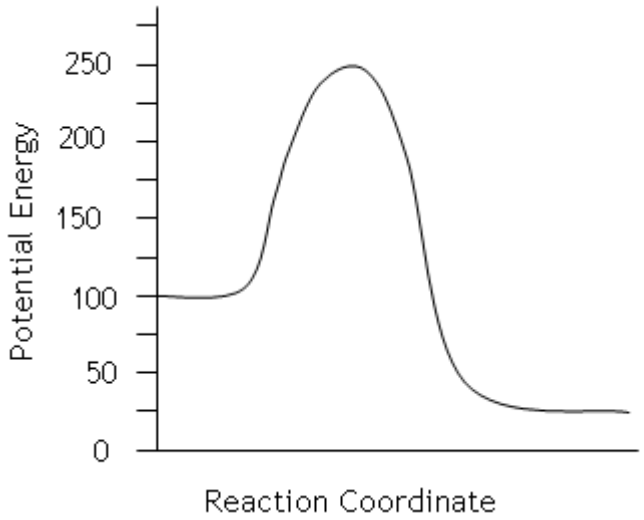
Answer the following questions:

1. Given the following reaction coordinate diagram



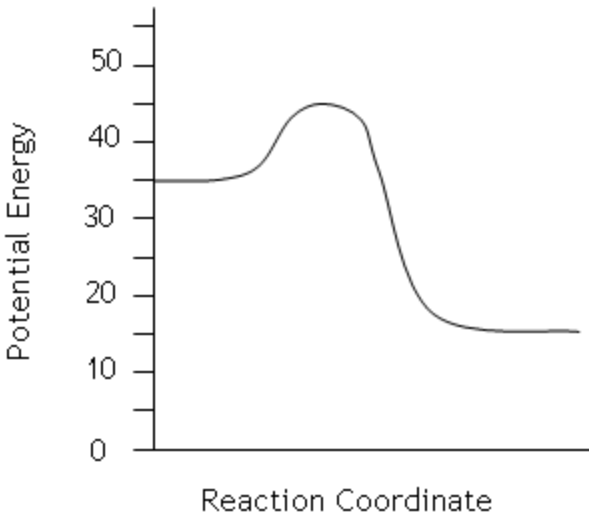
a) What is the activation energy of the reaction shown by the diagram?
b) What is the enthalpy change for this reaction?
c) Is this reaction endothermic or exothermic?

2. Given the following reaction coordinate diagram



a) What is the activation energy of the reaction in the diagram to the left?
b) What is the enthalpy change for this reaction?
c) Is this reaction endothermic or exothermic?
d) What would be the activation energy of the **reverse** reaction?

3. Given the following reaction coordinate diagram



a) What is the activation energy of the diagram to the left?
b) What is the enthalpy change for this reaction?
c) Is this reaction endothermic or exothermic?
d) What would be the activation energy of the reverse reaction?

4. What is the activated complex or transition state and how is it related to reaction rates? Label the position of the activated complex in each of the diagrams above.

5. Does every collision between reactant particles produce a reaction? Explain.

6. Explain why the enthalpy change for an exothermic reaction is negative, even though the container gets warmer.

1. According to the collision theory, it is not enough for particles to collide in order to have a successful reaction to produce products. Explain

2. Due to the number of requirements for a successful collision, according to the collision theory, the percentage of successful collisions is extremely small. Yet, chemical reactions are still observed at room temperature and some at very reasonable rates. Explain.

3. What is a basic assumption of the kinetic molecular theory?
    a. All particles will lose energy as the velocity increases
    b. All particles will lose energy as the temperature increases
    c. All particles will increase velocity as the temperature decreases
    d. All particles are in random motion
4. According to the collision theory, which of the following must happen in order for a reaction to be successful: i. particles must collide, ii. particles must have proper geometric orientation, iii. particles must have collisions with enough energy?

a. i, ii
b. i, iii
c. ii, iii
d. i, ii, iii

5. What would happen in a collision between two particles if there was insufficient kinetic energy and improper geometric orientation?
   a. The particles would rebound and there would be no reaction.
   b. The particles would keep bouncing off each other until they eventually react, therefore the rate would be slow.
   c. The particles would still collide but the byproducts would form.
   d. The temperature of the reaction vessel would increase.
6. In general, what effect does an increase in the concentration of the reactants have on the rate of the reaction? (explain using the collision theory)

7. How do changes each of the following factors affect the rate of a chemical reaction? Use diagrams to clarify your explanations.

   a) temperature
   b) particle size
   c) pressure

8. Which equation of the following pairs of equations would occur the fastest at under the same conditions. Explain your answers.

a. i) $Zn^{2+}(aq) + S^{2-}(aq) \rightarrow ZnS(s)$

   ii) $Zn(s) + S(s) \rightarrow ZnS(s)$

b. i) $2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(l)$

   ii) $Cu(s) + 2\ AgNO_3(aq) \rightarrow 2\ Ag^{+}(aq) + Cu(NO_3)_2(aq)$

c. i) $Pb(NO_3)_2(aq) + 2\ KI(aq) \rightarrow PbI_2(aq) + 2\ KNO_3(aq)$

   ii) $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$

d. i) $2\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$

   ii) $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

1. Given the following reaction mechanism:

$$H_2O_2 + I^- \rightarrow H_2O + IO^-$$
$$H_2O_2 + IO^- \rightarrow H_2O + O_2 + I^-$$

a) Write the balanced net reaction.

b) Identify the reaction intermediate(s).

c) Identify the catalyst(s).

2. Examine the following reaction mechanism:

$P + Q \rightarrow I_1 + R$ slow

$I_1 + P \rightarrow I_2 + W$ moderate

$I_2 + S \rightarrow T$ fast

a) Write out the net reaction.

b) Identify the overall rate of the net reaction.

c) Increasing [P] , increases the rate of the net reaction.

Increasing [Q] , increases the rate of the net reaction.

Increasing [S] , has no effect of the rate.

Explain why this is possible.

3. Write the net reaction for the mechanism.

$A + B \rightarrow I_1 + C$ very slow

$I_1 + A \rightarrow C + D$ fast

4. A proposed mechanism for the preparation of the poisonous liquid nitrobenzene ($C_6H_6NO_2$) is

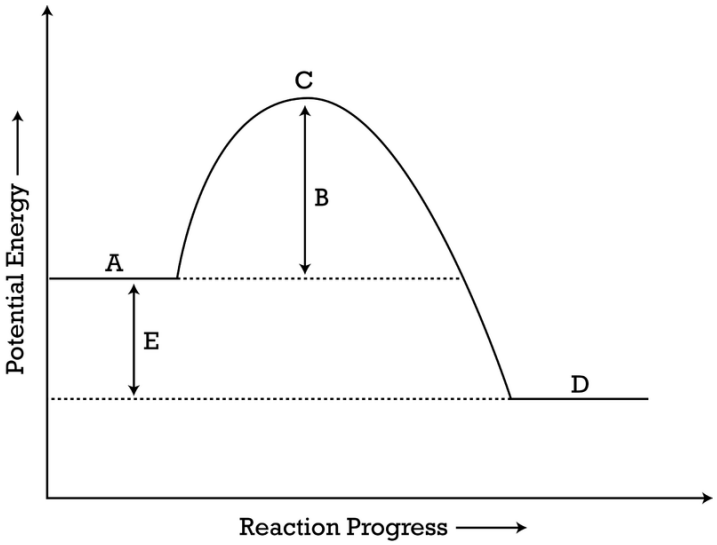
$$C_6H_6 + NO_2^+ \rightarrow C_6H_6NO_2^+ \quad \text{slow}$$
$$H_2SO_4 \rightarrow H^+ + HSO_4^- \quad \text{v. fast}$$
$$C_6H_6NO_2^+ + HSO_4^- \rightarrow C_6H_5NO_2 + H_2SO_4 \quad \text{fast}$$

a) What is the RDS? Why?

b) What is the net reaction?

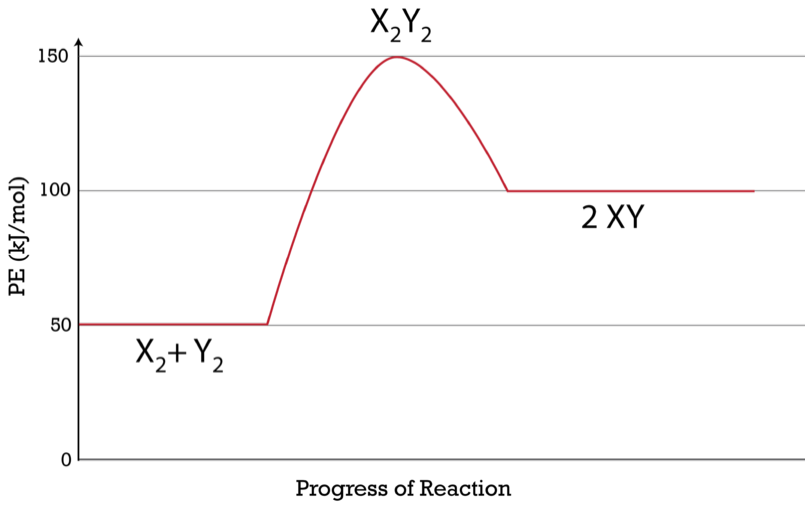
c) Without H_2SO_4 this is a very slow reaction. Explain.

Use the diagram below to answer questions 2 through 6.



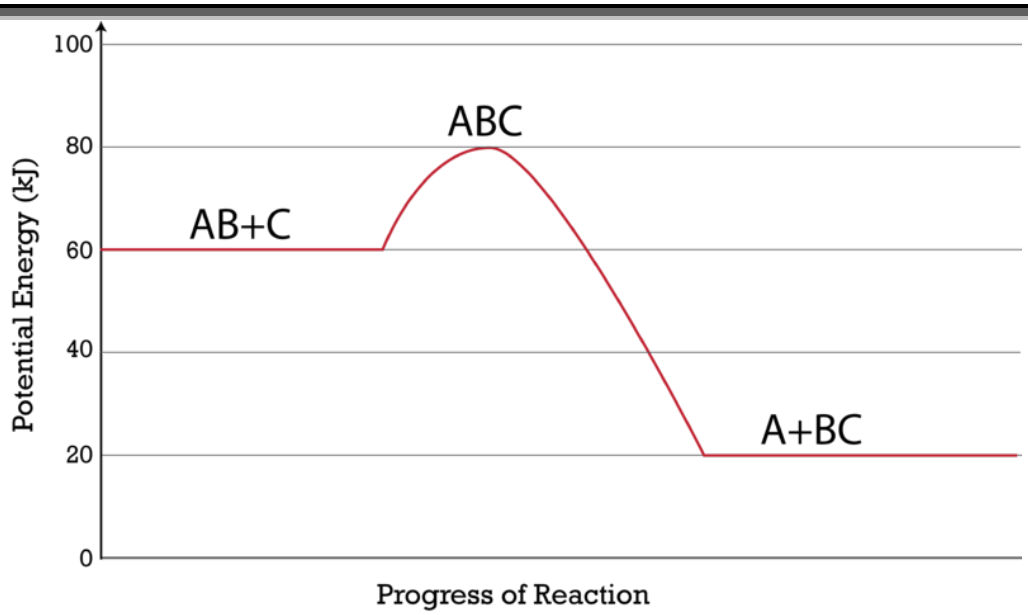
1. Which letter represents the activation energy barrier?
    a. a
    b. b
    c. c
    d. d
2. Which statement best describes the reaction?
    a. The reaction is exothermic in the forward reaction.
    b. The reaction is endothermic in the forward reaction.
    c. The reaction is exothermic in the reverse reaction.
    d. The reaction is exothermic only at high temperatures.
3. Which letter represents the change in enthalpy for the reaction?
    a. b
    b. c
    c. d
    d. e
4. Which letter represents the activated complex for the reaction?
    a. a
    b. b
    c. c
    d. d
5. What is an activated complex?
    a. a transitional species that can eventually be isolated
    b. a transitional species of that must be made before the products can be formed
    c. a reactant molecule breaking into a product molecule
    d. part of the activation energy barrier
6. For the following reaction, the activation energy is $60\ \text{kJ}$: $A_{2(g)} + 2\ B_{(g)} \rightarrow 2\ AB_{(g)}$. Draw a potential energy diagram properly labeling the following:
    a. the axes
    b. the reactants and products
    c. the activation energy
    d. the enthalpy

7. Use the following Potential Energy Diagram to answer questions 1 - 12.



8. Is the overall reaction as shown exothermic or endothermic? _____
9. What is the activation energy for the forward reaction? _____
10. What is the activation energy for the reverse reaction? _____
11. What is the enthalpy change for (ΔH) for the forward reaction? _____
12. What is the ΔH for the reverse reaction? _____
13. Is the reverse reaction exothermic or endothermic? _____
14. Which species is the activated complex? _____
15. Which species or group of species has the *highest* potential energy? _____
16. Which species or group of species has the *weakest* bonds? _____
17. Which species or group of species has the *strongest* bonds? _____
18. Which do you think would be *faster* at that the same temperature, the forward or reverse reaction?

    _____
19. What is the threshold energy for the forward reaction? _____
20. In general, as reactant particles begin a collision, the potential energy _____ (increases, decreases, stays the same) and the kinetic energy _____ (increases, decreases, stays the same).
21. Describe what happens to two reactant particles that collide with less than the activation energy?
22. Use the following Potential Energy Diagram to answer questions 23- 30.



23. What is the activation energy for the forward reaction? _____
24. What is the activation energy for the reverse reaction? _____
25. What is the ΔH for the forward reaction? _____
26. What is the ΔH for the reverse reaction? _____
27. Is the forward reaction exothermic or endothermic? _____
28. What is the threshold energy for the forward reaction? _____
29. Which bond is stronger, $A - B$ or $B - C$? _____
30. Give a reason for your answer in question 21.

Rate law worksheet

Answer the following questions. Be sure to show your work.

1. A first-order reaction initially proceeds at a rate of 0.500 mol/Ls.

   What will be the rate when half the starting material remains? When one-fourth of the starting material remains?

2. Assume the $N_2O(g)$ and $O_2(g)$ react according to the rate law

   $Rate = k[N_2O]\,[O_2]$

   How does the rate change if:
   a) the concentration of O_2 is doubled?
   b) the volume of the enclosing vessel is reduced by half?

1) Assume that $NO(g)$ and $H_2(g)$ react according to the rate law

   $Rate = k[NO]^2\,[H_2]$

   How does the rate change if:
   a) the concentration of H_2 is tripled?
   b) the concentration of NO is doubled?
   c) the volume of the enclosing vessel is reduced by half?

2) For the reaction: $A + 2\,B \rightarrow 2\,C$

[A] mol/L	[B] mol/L	Rate (mol/Lmin)
1.0	1.0	0.50
3.0	1.0	1.5
3.0	2.0	3.0

Find the rate law and calculate the value of the specific rate constant.

3) The reaction:

$I^-(aq) + OCl^-(aq) \rightarrow IO^-(aq) + Cl^-(aq)$ Was studied and the following data were obtained:

Trial	$[I^-]$ mol/L	$[OCl^-]$ mol/L	Initial Rate (mol/L•s)
1.0	0.12	0.18	7.91×10^{-2}
2.0	0.060	0.18	3.95×10^{-2}
3.0	0.24	0.090	7.91×10^{-2}
4.0	0.060	0.090	1.98×10^{-2}

a. What is the rate law?
b. What is the value of the rate constant?

4) For the reaction: $A + B + C \rightarrow D$

Trial	[A] mol/L	[B] mol/L	[C] mol/L	Initial Rate (mol/L•min)
1.0	1.0	2.0	0.50	0.35
2.0	2.0	2.0	0.50	1.40
3.0	2.0	1.0	0.50	1.40
4.0	1.0	2.0	1.0	0.70

Find the rate law and calculate the value of the specific rate constant.

5) For the reaction: $X + Y + Z \rightarrow S$

Trial	[X] mol/L	[Y] mol/L	[Z] mol/L	Initial Rate (mol/Lmin)
1.0	0.45	0.20	0.55	0.66
2.0	1.35	0.20	0.55	5.94
3.0	0.45	0.60	0.55	1.98
4.0	0.45	0.60	1.10	1.98

Find the rate law and calculate the value of the specific rate constant.

6) The reaction $CH_3COCH_3 + I_2 \rightarrow CH_3COCH_3 + HI$ is run in the presence of an excess of acid. The following data were obtained:

Trial	Initial $[I_2]$ (mol/L)	Initial $[CH_3COCH_3]$ (mol/L)	Initial Rate (mol/Ls)
1.0	0.100	0.100	1.16×10^{-7}
2.0	0.100	0.0500	5.79×10^{-8}
3.0	0.500	0.0500	5.77×10^{-8}

a. What is the rate law?
b. What is the value of the rate constant?

c. What is the rate if the concentration of CH_3COCH_3 is 0.0700 mol/L and the concentration of I_2 is 0.0850 mol/L
d. What is the concentration of I_2 if the concentration of CH_3COCH_3 is 0.0250 mol/L and the rate is 3.10×10^{8} mol/Ls?

7) For the reaction A + 2 B → C + D, the following data was collected

Trial	Initial [A] (mol/L)	Initial [B] (mol/L)	Initial Rate ($molL^{-1}s^{-1}$)
1.0	0.0100	0.0240	1.45×10^{-4}
2.0	0.0100	0.0120	7.25×10^{-5}
3.0	0.0200	0.0480	5.80×10^{-4}

What is the rate law?

8) For the reaction 3 A + B → 2 C + D, the following data was collected

Trial	Initial [A] (mol/L)	Initial [B] (mol/L)	Initial Rate ($molL^{-1}h^{-1}$)
1.0	0.0012	0.042	3.6×10^{-2}
2.0	0.00060	0.084	3.6×10^{-2}
3.0	0.00060	0.021	9.0×10^{-3}

What is the rate law?

9) For the elementary reaction $H_2 + I_2 \rightarrow 2$ HI
a) Write the rate law.
b) Find k if HI is produced at a rate of 1.0×10^{-4} mol/Lmin when $[H_2] = 0.025$ mol/L and $[I_2] = 0.050$ mol/L.
c) What is the rate of production of HI if the concentration of both reactants is 0.10 mol/L and the temperature is the same as in (b)?
d) How would the rate be affected if $[H_2]$ is doubled AND the $[I_2]$ is halved?

10) For the one step reaction A(g) + 2 B(g) ? C(g)
a) What is the rate law?
b) How does the rate change if
i) [A] is doubled?
ii) [B] is tripled?
iii) The volume of the container is doubled