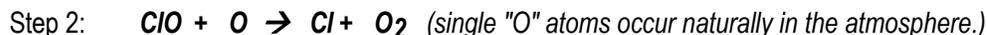# Worksheet Reaction Mechanisms

1. It is known that compounds called *chlorofluorocarbons* (C.F.C.s) (eg. $CFCl_3$) will break up in the presence of ultraviolet radiation, such as found in the upper atmosphere, forming single chlorine atoms:

    $$CFCl_3 \rightarrow CFCl_2 + Cl$$

    The Cl atoms then react with Ozone (O_3) as outlined in the following mechanism.

    Step 1: $Cl + O_3 \rightarrow ClO + O_2$

    Step 2: $ClO + O \rightarrow Cl + O_2$ *(single "O" atoms occur naturally in the atmosphere.)*

    a. Write the equation for the *overall reaction*. (Using steps 1 and 2)

    b. What is the *catalyst* in this reaction?

    c. Identify an *intermediate* in this reaction

    d. Explain how a *small* amount of chlorofluorocarbons can destroy a *large* amount of ozone.

    e. What breaks the bond in the $CFCl_3$ and releases the free Cl atom?

2. Given the following mechanism, answer the questions below:

    Step 1: $O_3 + NO \rightarrow NO_2 + O_2$ (slow)

    Step 2: $NO_2 + O \rightarrow NO + O_2$ (fast)

    a. Give the equation for the *overall reaction*.

    b. What could the *catalyst* be in this mechanism?

    c. What is an *intermediate* in this mechanism?

    d. Given that the **uncatalyzed** overall reaction is a *slow exothermic* reaction, draw a *potential energy graph* which shows the possible shape of the curve for the **uncatalyzed** reaction. On the same graph, show a possible curve for the **catalyzed** reaction.

3. Consider the following mechanism:

    Step 1: $H_2O_2 + I^- \rightarrow H_2O + IO^-$ *(slow)*

    Step 2: $H_2O_2 + IO^- \rightarrow H_2O + O_2 + I^-$ *(fast)*

    a. Give the equation for the overall reaction.

    b. What acts as a *catalyst* in this mechanism?

    c. What acts as an *intermediate* in this mechanism?

4. What is meant by the *rate determining step* in a reaction mechanism?

5. What is meant by a *reaction mechanism*?

6. How are reaction mechanisms determined?

7. Given the following *Potential Energy Diagram* for a 3 step reaction, answer the questions below it:
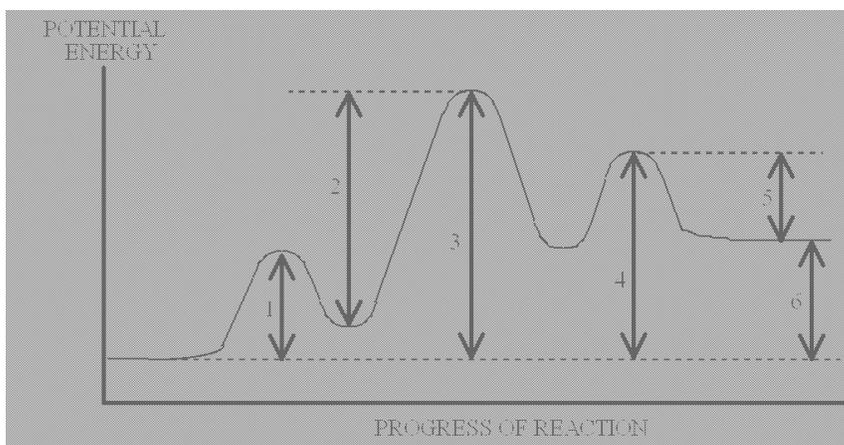
a. Which arrow indicates the *activation energy* for the *first* step of the reverse reaction? _____

b. Which arrow indicates the *activation energy* for the *first* step of the forward reaction? _____

c. Which arrow indicates the *activation energy* for the *second* step of the forward reaction? _____

d. Which arrow indicates the *enthalpy change* (ΔH) or "enthalpy change" for the *overall* **forward** reaction? _____

e. Which arrow indicates the *enthalpy change* (ΔH) or "enthalpy change" for the *overall* **reverse** reaction? _____

f. Which arrow indicates the *activation energy* for the *overall* forward reaction? _____

g. Which step would be the *rate determining step* in the *forward* reaction? _____

8. Given the reaction:

$$4HBr + O_2 \rightarrow 2H_2O + 2Br_2$$

a. Would you expect this reaction to take place in a single step? Why or why not?

b. This reaction is thought to take place by means of the following mechanism:

Step 1: **HBr + O_2 → HOOBr**   (slow)

Step 2: **HBr + HOOBr → 2HOBr**   (fast)

Step 3: **2HBr + 2HOBr → 2H_2O + 2Br_2**   (fast)

c. Identify the two *intermediates* _____

d. A catalyst is discovered which increases the rate of *Step 3*. How will this affect the rate of the *overall reaction*? Explain your answer.

e. A catalyst is discovered which increases the rate of *Step 1*. How will this affect the rate of the *overall reaction*?   Explain your answer.

f. Which step has the greatest ***activation energy***? _____

g. How many "bumps" will the potential energy diagram for the reaction mechanism have? _____

h. Which step is called the ***rate determining step*** in this mechanism? _____

i. In order to have successful collisions, the colliding particles must have **both** the proper amount of *energy* and the proper
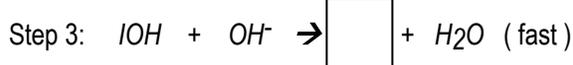
_____ .

j. On the set of axes below, draw the shape of the curve you might expect for the reaction in this question. The overall reaction is *exothermic*! Make sure you get the "bumps" the correct relative sizes.

Potential
Energy

Progress of Reaction
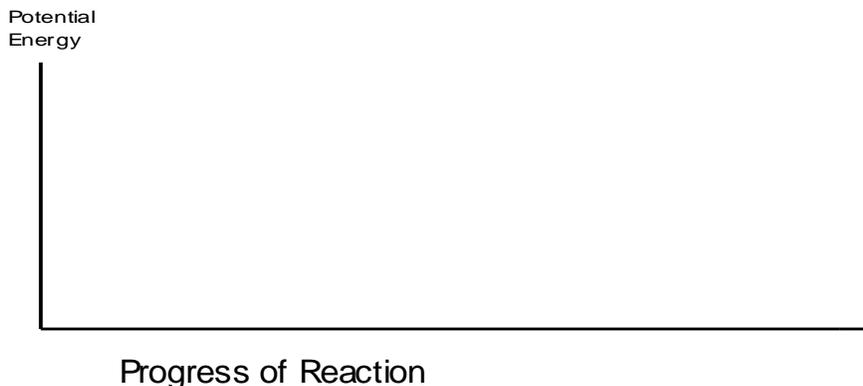
9.   The equation for an ***overall*** reaction is:

$$I^- + OCl^- \rightarrow IO^- + Cl^-$$

a) The following is a proposed *mechanism* for this reaction. One of the species has been left out. ***Determine what that species is and write it in the box.*** Make sure the *charge* is correct if it has one!

Step 1: $OCl^- + H_2O \rightarrow HOCl + OH^-$ (fast)

Step 2: $I^- + HOCl \rightarrow IOH + Cl^-$ (slow)

Step 3: $IOH + OH^- \rightarrow \boxed{} + H_2O$ (fast)

b) Which species in the mechanism above acts as a ***catalyst***?   _____

c) Which three species in the mechanism above are ***intermediates***?   _____

d) Step _____ is the ***rate determining step.***

e) On the set of axes below, draw the shape of the curve you might expect for the reaction in this question. The overall reaction is *endothermic*! Make sure you get the "bumps" the correct relative sizes.

Potential
Energy

Progress of Reaction

10. Given the following steps for a mechanism:

   Step 1: **Br$_2$** → **2Br**   *(fast)*

   Step 2: **Br + OCl$_2$** → **BrOCl + Cl**   *(slow)*

   Step 3: **Br + Cl** → **BrCl**   *(fast)*

   a) Write the equation for the **overall reaction**.

   b) A substance is added that *decreases* the *activation energy* for step **1**. Will this speed up, slow down, or have no effect on the rate of the overall reaction? Give a reason for your answer.

   c) Is there a **catalyst** in this mechanism? _____. If so, what is it? _____

   d) Is there an **intermediate** in this mechanism?_____. If so, what is it? _____

   e) Which step is the **rate determining step**? _____

11. The following **potential energy diagram** refers to a very slow one-step reaction of ozone (O$_3$) and oxygen atoms in the upper atmosphere.

   On the axis below, draw a potential energy diagram which could represent the *catalyzed mechanism* for the reaction:

   Step 1: **O$_3$ + NO** → **NO$_2$ + O$_2$** (slow)

   Step 2: **NO$_2$ + O** → **NO + O$_2$** (fast)
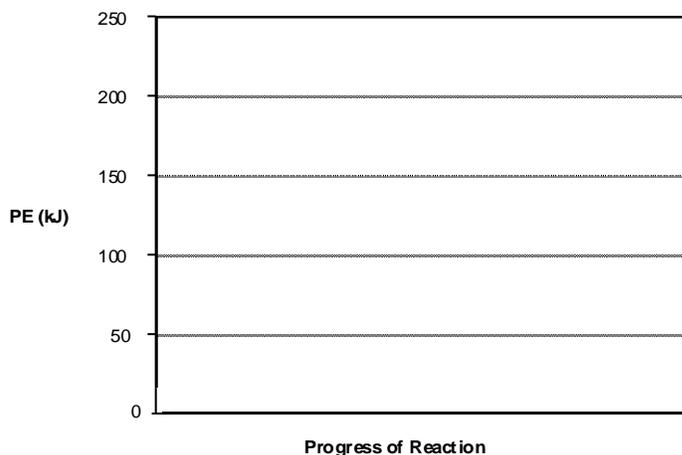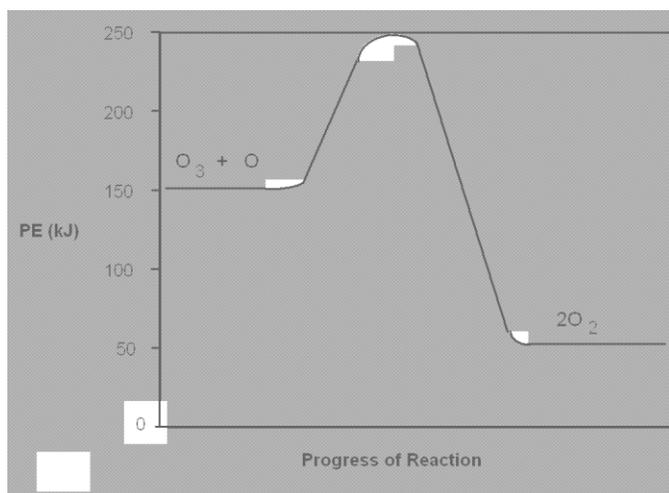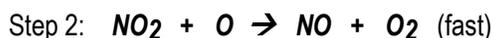
12. A certain chemical can provide a reaction with an alternate mechanism having a *greater* activation energy. What will happen to the *rate of the reaction* when this chemical is added? Explain your answer.

13. The following overall reaction is *fast* at room temperature:

$$H^+ + I^- + H_2O_2 \rightarrow H_2O + HOI$$

A student proposes the following two-step mechanism for the above reaction:

Step 1 : $H^+ + H^+ + H_2O_2 \rightarrow H_4O_2^{2+}$

Step 2 : $H_4O_2^{2+} + I^- \rightarrow H_2O + HOI + H^+$
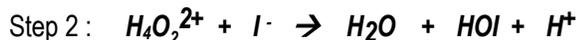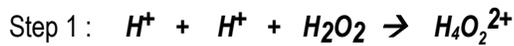
Would you *agree* or *disagree* with this proposed mechanism? Explain your answer

14. Consider the following reaction:

$$CO + NO_2 \rightarrow CO_2 + NO$$

a) The *first step* in each of two proposed reaction mechanisms for the above reaction is listed below. If each proposed reaction mechanism consists of only *two* steps, **determine the second step for each mechanism**.

Proposed Mechanism One:

Step 1: $2NO_2 \rightarrow NO_3 + NO$ (slow)

Step 2: _____ (fast)

Proposed Mechanism Two:

Step 1: $2NO_2 \rightarrow N_2O_4$ (fast)

Step 2: _____ (slow)

b) Experimental data show that the rate of the reaction is *not* affected by a change in the [CO]. Which of these two mechanisms would be consistent with these data? Explain your answer.
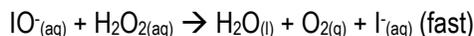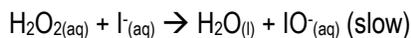
15.   The empirical rate law for the reaction is

$$Rate = k[NO_2][F_2]$$

Which of the following mechanisms is consistent with this rate law?

A)	B)	C)
$NO_{2\ (g)} + F_{2\ (g)} <==> NO_2F_{(g)} + F_{(g)}$ fast	$NO_{2\ (g)} + F_{2(g)} <==> NO_2F_{(g)} + F_{(g)}$ slow	$F_{2(g)} <==> F_{(g)} + F_{(g)}$ slow
$NO_{2(g)} + F_{(g)} ---> NO_2F_{(g)}$ slow	$NO_{2(g)} + F_{(g)} ---> NO_2F_{(g)}$ fast	$2NO_{2(g)} + 2F_{(g)} ---> 2NO_2F_{(g)}$ fast

16.   The decomposition of hydrogen peroxide is catalyzed by the iodide ion. The catalyzed reaction is thought to proceed by a two-step mechanism:

$$H_2O_{2(aq)} + I^-_{(aq)} \rightarrow H_2O_{(l)} + IO^-_{(aq)} \text{ (slow)}$$
$$IO^-_{(aq)} + H_2O_{2(aq)} \rightarrow H_2O_{(l)} + O_{2(g)} + I^-_{(aq)} \text{ (fast)}$$

a. Predict the rate law for the overall process. _____
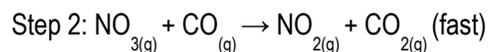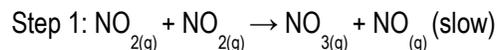
b. Write the chemical equation for the overall process.

c. Identify the intermediate, if any, in the mechanism. _____

17.   The reaction: $NO_{2(g)} + CO_{(g)} \rightarrow NO_{(g)} + CO_{2(g)}$ is found to be second order with respect to $[NO_2]$ and zero order with respect to $[CO]$.

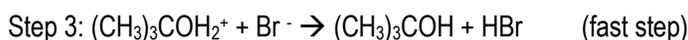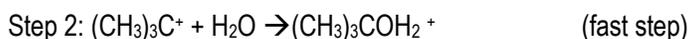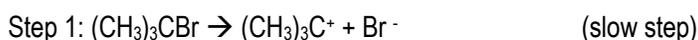The rate law for this process was found to be, $r = k[NO_2]^2$

Is this rate law consistent with the information given?

The following mechanism has been proposed:

$\qquad$ Step 1: $NO_{2(g)} + NO_{2(g)} \rightarrow NO_{3(g)} + NO_{(g)}$ (slow)

$\qquad$ Step 2: $NO_{3(g)} + CO_{(g)} \rightarrow NO_{2(g)} + CO_{2(g)}$ (fast)

Is this reaction mechanism consistent with the observed kinetics?

18.   Consider the following reaction mechanism.

$\quad$ Step 1: $(CH_3)_3CBr \rightarrow (CH_3)_3C^+ + Br^-$ $\qquad\qquad$ (slow step)

$\quad$ Step 2: $(CH_3)_3C^+ + H_2O \rightarrow (CH_3)_3COH_2^+$ $\qquad\qquad$ (fast step)

$\quad$ Step 3: $(CH_3)_3COH_2^+ + Br^- \rightarrow (CH_3)_3COH + HBr$ $\quad$ (fast step)

a)   What is the net reaction?

b)   What are the intermediate compounds?

c) What is the rate determining step? _____

d) What is the rate law? _____

e) What is the order of the reaction with respect to each reactant in the net reaction?

19.   The following reaction $2A + B + C \rightarrow A_2BC$ $\qquad$ was found to have the following rate law:

$\qquad\qquad\qquad\qquad$ $r = k[A][B]$

Propose a reaction mechanism that suits this rate law.