AP® CHEMISTRY
2010 SCORING GUIDELINES (Form B)

Question 6
(8 points)

$$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$$

The table below gives data for a reaction rate study of the reaction represented above.

Experiment	Initial $[H_2]$ (mol L^{-1})	Initial $[Cl_2]$ (mol L^{-1})	Initial Rate of Formation of HCl (mol L^{-1} s^{-1})
1	0.00100	0.000500	1.82×10^{-12}
2	0.00200	0.000500	3.64×10^{-12}
3	0.00200	0.000250	1.82×10^{-12}

(a) Determine the order of the reaction with respect to H_2 and justify your answer.

The order of the reaction with respect to H_2 is 1. Comparing experiments 1 and 2, doubling the initial concentration of H_2 while keeping the initial concentration of Cl_2 constant results in a doubling of the reaction rate.	One point is earned for the correct order with justification.

(b) Determine the order of the reaction with respect to Cl_2 and justify your answer.

The order of the reaction with respect to Cl_2 is 1. Comparing experiments 2 and 3, halving the initial concentration of Cl_2 while keeping the initial concentration of H_2 constant results in a halving of the reaction rate.	One point is earned for the correct order with justification.

(c) Write the overall rate law for the reaction.

rate $= k\,[H_2][Cl_2]$	One point is earned for a rate law consistent with part (a) and part (b).

(d) Write the units of the rate constant.

$k = \dfrac{rate}{[H_2][Cl_2]} = \dfrac{\text{mol } L^{-1} s^{-1}}{\text{mol } L^{-1} \text{ mol } L^{-1}}$ $= \dfrac{s^{-1}}{\text{mol } L^{-1}} = L\ \text{mol}^{-1}\ s^{-1}$	One point is earned for units consistent with part (c).

Question 6 (continued)

(e) Predict the initial rate of the reaction if the initial concentration of H_2 is 0.00300 mol L^{-1} and the initial concentration of Cl_2 is 0.000500 mol L^{-1}.

For this reaction, the initial concentration of Cl_2 is the same as in Experiment 1 but the initial concentration of H_2 is three times as large. And because the reaction is first order with respect to each reactant, the initial rate of the reaction would be 5.46×10^{-12} mol L^{-1} s^{-1}, which is three times the rate of the initial rate of the reaction in Experiment 1.	One point is earned for the correct numerical answer or correct multiplier consistent with the rate law from part (c).

The gas-phase decomposition of nitrous oxide has the following two-step mechanism.

Step 1: $N_2O \rightarrow N_2 + O$

Step 2: $O + N_2O \rightarrow N_2 + O_2$

(f) Write the balanced equation for the overall reaction.

$2\ N_2O \rightarrow 2\ N_2 + O_2$	One point is earned for the correct balanced equation.

(g) Is the oxygen atom, O, a catalyst for the reaction or is it an intermediate? Explain.

The O atom is an intermediate because it is formed and then consumed during the course of the reaction. (Had it been a catalyst, it would have been present both at the beginning and the end of the reaction.)	One point is earned for the correct choice with explanation.

(h) Identify the slower step in the mechanism if the rate law for the reaction was determined to be *rate* = $k[N_2O]$. Justify your answer.

Step 1 is slower because N_2O appears in Step 1 as the single reactant, which is consistent with the given rate law.	One point is earned for the correct choice with justification.

6A, 1

$$H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$$

6. The table below gives data for a reaction rate study of the reaction represented above.

Experiment	Initial $[H_2]$ (mol L^{-1})	Initial $[Cl_2]$ (mol L^{-1})	Initial Rate of Formation of HCl (mol L^{-1} s^{-1})
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2	0.00200	0.000500	3.64×10^{-12}
3	0.00200	0.000250	1.82×10^{-12}

(a) Determine the order of the reaction with respect to H_2 and justify your answer.

(b) Determine the order of the reaction with respect to Cl_2 and justify your answer.

(c) Write the overall rate law for the reaction.

(d) Write the units of the rate constant.

(e) Predict the initial rate of the reaction if the initial concentration of H_2 is 0.00300 mol L^{-1} and the initial concentration of Cl_2 is 0.000500 mol L^{-1}.

The gas-phase decomposition of nitrous oxide has the following two-step mechanism.

Step 1: $N_2O \rightarrow N_2 + O$

Step 2: $O + N_2O \rightarrow N_2 + O_2$

(f) Write the balanced equation for the overall reaction.

(g) Is the oxygen atom, O, a catalyst for the reaction or is it an intermediate? Explain.

(h) Identify the slower step in the mechanism if the rate law for the reaction was determined to be *rate* = $k[N_2O]$. Justify your answer.

a. $\frac{\text{trial 2}}{\text{trial 1}}$ $\quad \frac{3.64 \times 10^{-12}}{1.82 \times 10^{-12}} = \frac{k[.00200]^x[.000500]^y}{k[.00100]^x[.000500]^y}$

$2 = 2^x$

$x = 1$

Order with respect to H_2 is first order. (coefficient is 1)

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

b. trial 2 / trial 3 $\frac{3.64\times10^{-12} = k[.00200]^1[.000500]^y}{1.82\times10^{-12} = k[.00200]^1[.000250]^y}$

$2 = 2^y$

$y = 1$

Order with respect to Cl_2 is first order (coefficient is 1)

c. rate = $k[H_2][Cl_2]$

d. overall order = 2 unit of rate constant: $L/mol \cdot s$

$2 - 1 = 1$

e. It will be like tripling experiment 1.

1.82×10^{-12}

$\times 3$

5.46×10^{-12} mol/L·s (initial rate of formation)

f. ~~$O + N_2O + N_2O \rightarrow N_2 + O + N_2 + O_2$~~

$2N_2O \rightarrow 2N_2 + O_2$

g. O is an intermediate because it is made in step 1 and then used up in step 2. Intermediates are made and used.

h. The slow step must be step 1 because its rate law is also rate = $k[N_2O]$. The slow steps determine the rate law of the entire mechanism.

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$$H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$$

6. The table below gives data for a reaction rate study of the reaction represented above.

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(a) Determine the order of the reaction with respect to H_2 and justify your answer.

(b) Determine the order of the reaction with respect to Cl_2 and justify your answer.

(c) Write the overall rate law for the reaction.

(d) Write the units of the rate constant.

(e) Predict the initial rate of the reaction if the initial concentration of H_2 is 0.00300 mol L^{-1} and the initial concentration of Cl_2 is 0.000500 mol L^{-1}.

The gas-phase decomposition of nitrous oxide has the following two-step mechanism.

Step 1: $N_2O \rightarrow N_2 + O$ $\quad 2N_2O \rightarrow 2N_2 + O_2$

Step 2: $O + N_2O \rightarrow N_2 + O_2$

(f) Write the balanced equation for the overall reaction.

(g) Is the oxygen atom, O, a catalyst for the reaction or is it an intermediate? Explain.

(h) Identify the slower step in the mechanism if the rate law for the reaction was determined to be *rate* = $k[N_2O]$. Justify your answer.

(a) First order with respect to $[H_2]$
If $[Cl_2]$ kept constant, when $[H_2]$ Doubled, the Rate Doubled.

(b) First order, because when $[H_2]$ kept constant, As $[Cl_2]$ decrease to the half, the rate also lowered to the half.

(c) $R = K[H_2][Cl_2]$

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

(d) $k = \frac{\text{Rate}}{[H_2][Cl_2]} \Rightarrow \frac{\frac{mol}{L \cdot s}}{\left(\frac{mol}{L}\right)^2} = \frac{L\ s^{-1}}{mol} = L\ s^{-1}\ mol^{-1}$

$= \frac{\frac{1}{s}}{\frac{mol}{L}} = \frac{L\ \frac{1}{s}}{mol} = \frac{\frac{L}{s}}{mol} = \left(\frac{L}{s \cdot mol}\right)$

(e) $k = \frac{R}{[H_2][Cl_2]} = \frac{1.82 \times 10^{-12}}{(0.001)(0.0005)} =$

Rate $= k[H_2][Cl_2]$

$= k[0.003][0.0005]$ = initial rate

(f) $N_2O_2 \rightarrow N_2 + O$

$O + N_2O \rightarrow N_2 + O_2$

overall reaction: $2N_2O \rightarrow 2N_2 + O_2$

(g) O is an intermediate, because it appears in the first and second step but .

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 6C1

$$H_2(g) + Cl_2(g) \rightarrow 2\,HCl(g)$$

6. The table below gives data for a reaction rate study of the reaction represented above.

Experiment	Initial $[H_2]$ (mol L^{-1})	Initial $[Cl_2]$ (mol L^{-1})	Initial Rate of Formation of HCl (mol L^{-1} s^{-1})
1	0.00100	0.000500	1.82×10^{-12}
2	0.00200	0.000500	3.64×10^{-12}
3	0.00200	0.000250	1.82×10^{-12}

(a) Determine the order of the reaction with respect to H_2 and justify your answer.

(b) Determine the order of the reaction with respect to Cl_2 and justify your answer.

(c) Write the overall rate law for the reaction.

(d) Write the units of the rate constant.

(e) Predict the initial rate of the reaction if the initial concentration of H_2 is 0.00300 mol L^{-1} and the initial concentration of Cl_2 is 0.000500 mol L^{-1}.

The gas-phase decomposition of nitrous oxide has the following two-step mechanism.

Step 1: $N_2O \rightarrow N_2 + O$

Step 2: $O + N_2O \rightarrow N_2 + O_2$

(f) Write the balanced equation for the overall reaction.

(g) Is the oxygen atom, O, a catalyst for the reaction or is it an intermediate? Explain.

(h) Identify the slower step in the mechanism if the rate law for the reaction was determined to be *rate* = $k[N_2O]$. Justify your answer.

6.(a) First order

(b) First order

(c) $R = k[H_2][Cl_2]$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

(d) $mol\,L^{-1}s^{-1} = K(mol\,L^{-1})(mol\,L^{-1})$

$K = \dfrac{mol\,L^{-1}s^{-1}}{mol\,L^{-1} \cdot mol\,L^{-1}}$

$= \dfrac{L}{mol \cdot s}$

(e) $K = \dfrac{R}{[H_2][Cl_2]}$

$= \dfrac{1.82 \times 10^{-12}\ mol\,L^{-1}s^{-1}}{(0.00100\ mol\,L^{-1})(0.000500\ mol\,L^{-1})}$

$R = K[H_2][Cl_2]$

$= \left(\dfrac{1.82 \times 10^{-12}\ mol\,L^{-1}s^{-1}}{(0.00100\ mol\,L^{-1})(0.000500\ mol\,L^{-1})}\right)(0.00300\ mol\,L^{-1})(0.000500\ mol\,L^{-1})$

$= 1.82 \times 10^{-12}\ mol\,L^{-1}s^{-1} \times 3$

$= 5.46 \times 10^{-12}\ mol\,L^{-1}s^{-1}$

(f) $N_2O \rightarrow N_2 + O$

$O + N_2O \rightarrow N_2 + O_2$

$2N_2O \rightarrow 2N_2 + O_2$

(g) Oxygen atom is an intermediate because it can be removed in an overall reaction.

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AP® CHEMISTRY
2010 SCORING COMMENTARY (Form B)

Question 6

Sample: 6A
Score: 8

This response earned all 8 points: 1 point for part (a), 1 point for part (b), 1 point for part (c), 1 point for part (d), 1 point for part (e), 1 point for part (f), 1 point for part (g), and 1 point for part (h).

Sample: 6B
Score: 5

This response earned 5 of the possible 8 points. In part (e) the point was not earned because the student does not predict the initial rate of the reaction after the concentration of hydrogen gas is tripled. In part (g) the point was not earned because the student does not include an acceptable explanation as to why O is an intermediate. Part (h) is not addressed.

Sample: 6C
Score: 4

This response earned 4 of the possible 8 points. The points were not earned in parts (a) and (b) because the student gives no indication as to why the reaction is first order with respect to H_2 or Cl_2. In part (c) 1 point was earned for correctly writing the rate law using the stated orders from parts (a) and (b). In part (d) 1 point was earned for giving the units of the rate constant. In part (e) 1 point was earned for correctly predicting the initial rate of the reaction after the concentration of hydrogen gas is tripled. In part (f) 1 point was earned for writing the correct overall reaction. In part (g) the point was not earned because the student does not include an acceptable explanation as to why O is an intermediate. Part (h) is not addressed.