$$A(g) + B(g) \rightarrow C(g) + D(g)$$

2. For the gas-phase reaction represented above, the following experimental data were obtained.

Experiment	Initial [A] (mol L^{-1})	Initial [B] (mol L^{-1})	Initial Reaction Rate (mol L^{-1} s^{-1})
1	0.033	0.034	6.67×10^{-4}
2	0.034	0.137	1.08×10^{-2}
3	0.136	0.136	1.07×10^{-2}
4	0.202	0.233	?

(a) Determine the order of the reaction with respect to reactant A. Justify your answer.

(b) Determine the order of the reaction with respect to reactant B. Justify your answer.

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

(d) Determine the value of the rate constant, k, for the reaction. Include units with your answer.

(e) Calculate the initial reaction rate for experiment 4.

(f) The following mechanism has been proposed for the reaction.

Step 1: $B + B \rightarrow E + D$ *slow*

Step 2: $E + A \rightleftarrows B + C$ *fast equilibrium*

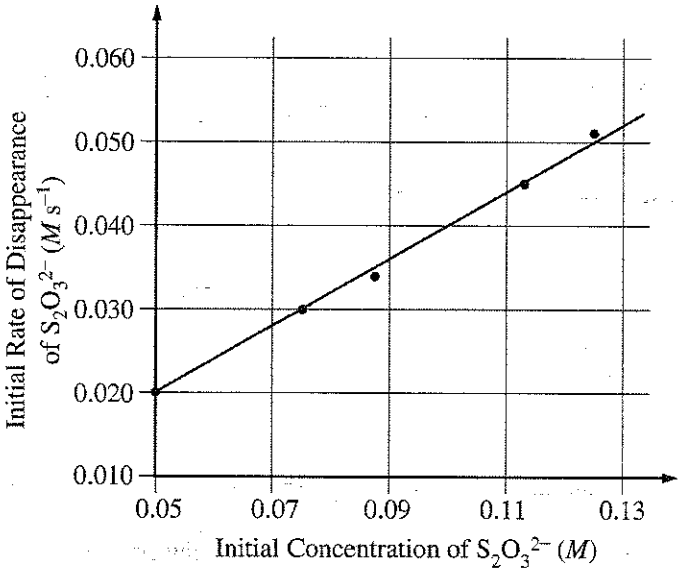
Provide two reasons why the mechanism is acceptable.

(g) In the mechanism in part (f), is species E a catalyst, or is it an intermediate? Justify your answer.

$$S_2O_3^{2-}(aq) \xrightarrow{H^+} SO_3^{2-}(aq) + S(s)$$

2. A student performed an experiment to investigate the decomposition of sodium thiosulfate, $Na_2S_2O_3$, in acidic solution, as represented by the equation above. In each trial the student mixed a different concentration of sodium thiosulfate with hydrochloric acid at constant temperature and determined the rate of disappearance of $S_2O_3^{2-}(aq)$. Data from five trials are given below in the table on the left and are plotted in the graph on the right.

Trial	Initial Concentration of $S_2O_3^{2-}$ (aq) (M)	Initial Rate of Disappearance of $S_2O_3^{2-}$ (aq) $(M\ s^{-1})$
1	0.050	0.020
2	0.075	0.030
3	0.088	0.034
4	0.112	0.045
5	0.125	0.051



(a) Identify the independent variable in the experiment.

(b) Determine the order of the reaction with respect to $S_2O_3^{2-}$. Justify your answer by using the information above.

(c) Determine the value of the rate constant, k, for the reaction. Include units in your answer. Show how you arrived at your answer.

(d) In another trial the student mixed 0.10 M $Na_2S_2O_3$ with hydrochloric acid. Calculate the amount of time it would take for the concentration of $S_2O_3^{2-}$ to drop to 0.020 M.

(e) On the graph above, sketch the line that shows the results that would be expected if the student repeated the five trials at a temperature lower than that during the first set of trials.

GO ON TO THE NEXT PAGE.

$$8\ H^+(aq) + 4\ Cl^-(aq) + MnO_4^-(aq) \rightarrow 2\ Cl_2(g) + Mn^{3+}(aq) + 4\ H_2O(l)$$

3. $Cl_2(g)$ can be generated in the laboratory by reacting potassium permanganate with an acidified solution of sodium chloride. The net-ionic equation for the reaction is given above.

   (a) A 25.00 mL sample of 0.250 *M* NaCl reacts completely with excess $KMnO_4(aq)$. The $Cl_2(g)$ produced is dried and stored in a sealed container. At 22°C the pressure of the $Cl_2(g)$ in the container is 0.950 atm.

   (i) Calculate the number of moles of $Cl^-(aq)$ present before any reaction occurs.

   (ii) Calculate the volume, in L, of the $Cl_2(g)$ in the sealed container.

An initial-rate study was performed on the reaction system. Data for the experiment are given in the table below.

Trial	$[Cl^-]$	$[MnO_4^-]$	$[H^+]$	Rate of Disappearance of MnO_4^- in $M\ s^{-1}$
1	0.0104	0.00400	3.00	2.25×10^{-8}
2	0.0312	0.00400	3.00	2.03×10^{-7}
3	0.0312	0.00200	3.00	1.02×10^{-7}

   (b) Using the information in the table, determine the order of the reaction with respect to each of the following. Justify your answers.

   (i) Cl^-

   (ii) MnO_4^-

   (c) The reaction is known to be third order with respect to H^+. Using this information and your answers to part (b) above, complete both of the following:

   (i) Write the rate law for the reaction.

   (ii) Calculate the value of the rate constant, k, for the reaction, including appropriate units.

   (d) Is it likely that the reaction occurs in a single elementary step? Justify your answer.

STOP

If you finish before time is called, you may check your work on this part only.
Do not turn to the other part of the test until you are told to do so.

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

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.

STOP

END OF EXAM

6. In an experiment, all the air in a rigid 2.0 L flask is pumped out. Then some liquid ethanol is injected into the sealed flask, which is held at 35°C. The amount of liquid ethanol initially decreases, but after five minutes the amount of liquid ethanol in the flask remains constant. Ethanol has a boiling point of 78.5°C and an equilibrium vapor pressure of 100 torr at 35°C.

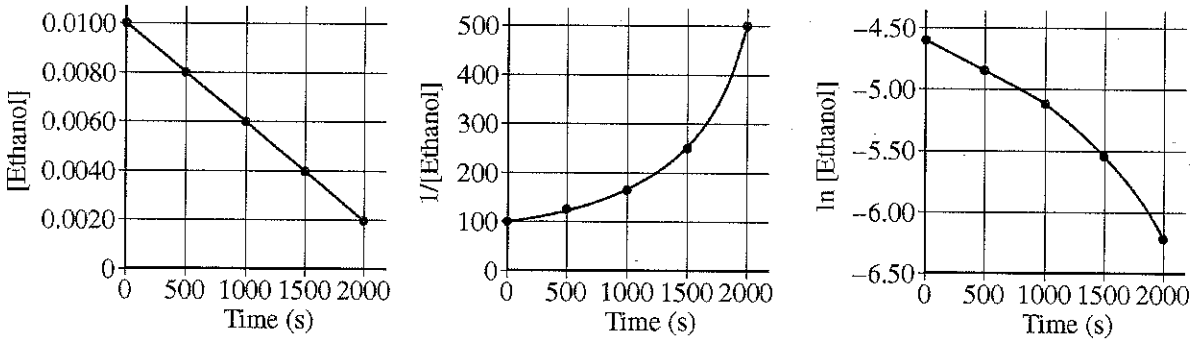
   (a) When the amount of liquid ethanol in the flask is constant, is the pressure in the flask greater than, less than, or equal to 100 torr? Justify your answer.

   (b) The flask is then heated to 45°C, and the pressure in the flask increases. In terms of kinetic molecular theory, provide TWO reasons that the pressure in the flask is greater at 45°C than at 35°C.

In a second experiment, which is performed at a much higher temperature, a sample of ethanol gas and a copper catalyst are placed in a rigid, empty 1.0 L flask. The temperature of the flask is held constant, and the initial concentration of the ethanol gas is 0.0100 *M*. The ethanol begins to decompose according to the chemical reaction represented below.

$$CH_3CH_2OH(g) \xrightarrow{Cu} CH_3CHO(g) + H_2(g)$$

The concentration of ethanol gas over time is used to create the three graphs below.



   (c) Given that the reaction order is zero, one, or two, use the information in the graphs to respond to the following.

      (i) Determine the order of the reaction with respect to ethanol. Justify your answer.

      (ii) Write the rate law for the reaction.

      (iii) Determine the rate constant for the reaction, including units.

   (d) The pressure in the flask at the beginning of the experiment is 0.40 atm. If the ethanol completely decomposes, what is the final pressure in the flask?

STOP

END OF EXAM