1.1. Rate determining step

1. For each of the everyday processes described below, identify the step that slows the process down.

(a) Making a cup of tea.

Step 1: Get a mug out of the cupboard
Step 2: Add a tea bag
Step 3: Boil the water
Step 4: Leave the tea bag to stew

(b) Playing with a model helicopter received as a Christmas present.

Step 1: Spot the present under the tree
Step 2: Unwrap the present
Step 3: Charge the batteries for 24 h
Step 4: Play with the helicopter

(c) Getting out of the house in the morning on time.

Step 1: Alarm goes off
Step 2: Get out of bed
Step 3: Have a shower
Step 4: Eat breakfast

The overall rate of these processes is controlled by the rate of the slowest step. For a chemical reaction we call this step the rate determining or rate limiting step.

For each of the multi-step reactions below, write the overall equation for the reaction and identify the rate limiting step.

2. Step 1: \( \text{CH}_3\text{Br} \xrightarrow{\text{slow}} \text{CH}_3^+ + \text{Br}^- \)  
   Step 2: \( \text{CH}_3^+ + \text{OH}^- \xrightarrow{\text{fast}} \text{CH}_3\text{OH} \)  
   Overall equation .................................................................
   Rate limiting step .................................................................

3. Step 1: \( \text{NO} + \text{NO} \xrightarrow{\text{slow}} \text{N}_2\text{O}_2 \)  
   Step 2: \( \text{N}_2\text{O}_2 + \text{O}_2 \xrightarrow{\text{fast}} 2 \text{NO}_2 \)  
   Overall equation .................................................................
   Rate limiting step .................................................................

4. Step 1: \( \text{NO} + \text{NO} \xrightarrow{\text{fast}} \text{N}_2\text{O}_2 \)  
   Step 2: \( \text{N}_2\text{O}_2 + \text{H}_2 \xrightarrow{\text{slow}} \text{N}_2\text{O} + \text{H}_2\text{O} \)  
   Step 3: \( \text{N}_2\text{O} + \text{H}_2 \xrightarrow{\text{fast}} \text{N}_2 + \text{H}_2\text{O} \)  
   Overall equation .................................................................
   Rate limiting step .................................................................
   (6 marks)

BONUS MARK

In a chemical reaction, any step that occurs after the rate determining step will not affect the rate. Therefore any species that are involved in the mechanism after the rate determining step do not appear in the rate expression. Use this information to predict which of the options below is the correct rate expression for the reaction shown in question 2.

(a) Rate = \( k [\text{CH}_3\text{Br}] \)  
(b) Rate = \( k [\text{CH}_3\text{Br}][\text{OH}^-] \)  

(1 mark)
1. Kinetics answers

1.1. Rate determining step

1.  (a) Step 3 Boil the water
(b) Step 3 Charge the batteries for 24 h
(c) Step 2 Get out of bed (although this may depend on the individual!) (3 marks)

2. **Overall equation:** CH$_3$Br + OH$^-$ → CH$_3$OH + Br$^-$

   *Rate limiting step:* CH$_3$Br → CH$_3$ + Br$^-$ (Step 1) (2 marks)

3. **Overall equation:** 2 NO + O$_2$ → 2 NO$_2$

   *Rate limiting step:* NO + NO → N$_2$O (Step 1) (2 marks)

4. **Overall equation:** 2 NO + 2 H$_2$ → N$_2$ + 2 H$_2$O

   *Rate limiting step:* N$_2$O$_2$ + H$_2$ → N$_2$O + H$_2$O (Step 2) (2 marks)

**BONUS MARK**

   Answer = (a) Rate = $k$ [CH$_3$Br] (1 mark)

1.2. Calculating reaction rate

1. The rate of a reaction is the change in concentration of reactants or products per unit time (2 marks)

2. (a) i. 2.0 × 10$^{-4}$ mol dm$^{-3}$ s$^{-1}$
   ii. 1.3 × 10$^{-4}$ mol dm$^{-3}$ s$^{-1}$
   iii. 5.5 × 10$^{-5}$ mol dm$^{-3}$ s$^{-1}$ (1 mark for each correct value, 1 mark for the correct units for rate)

   ![Graph](image)

   (b) The reaction is first order with respect to C$_4$H$_9$Cl. (1 mark)