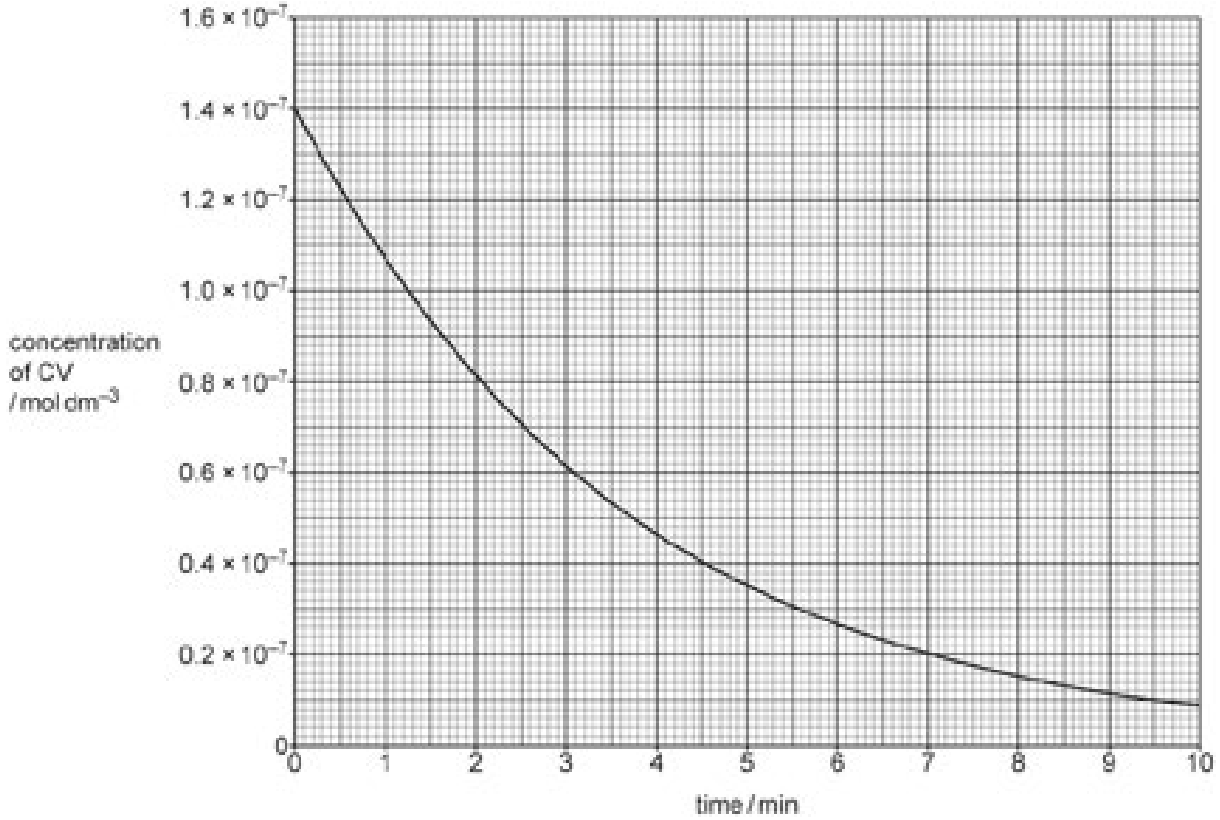
1. Crystal violet (CV) is a purple dye. In the presence of an alkali, CV reacts to form a colourless product.

A student uses a colorimeter to investigate the rate of the reaction between CV and sodium hydroxide, NaOH.

- The student mixes 10.0 cm^3 of 2.8×10^{-7} mol dm^{-3} CV with 10.0 cm^3 of 0.016 mol dm^{-3} NaOH.
- A large excess of NaOH is used, so that the reaction is effectively zero-order with respect to OH^- ions.
- The student places a sample of the reaction mixture in a colorimeter and measures the absorbance over time.

The student uses the absorbance readings to calculate the concentration of CV and plots a graph of concentration of CV against time, as shown below.



Use the graph to determine the order of reaction with respect to CV, the rate of the reaction at three minutes and the rate constant, *k*.

Your answer must show full working on the graph and on the lines below.

[6]

2. Fluorine, F_2, reacts with nitrogen dioxide, NO_2, to form nitryl fluoride, NO_2F, as shown in **Reaction 20.1** below.

$F_2 + 2NO_2 \rightarrow 2NO_2F$ **Reaction 20.1**

The mechanism for this reaction involves two steps. **Step 1** is the 'slow' step and **Step 2** is the 'fast' step.

The equation for **Step 2** is shown below:

$F + NO_2 \rightarrow NO_2F$

Suggest the equation for **Step 1** and the rate equation for **Reaction 20.1**.

Equation for **Step 1**:

Rate equation for **Reaction 20.1**:

[2]

3. A graph of ln(k) is plotted against 1 / T for a reaction.
(k = rate constant, T = temperature in K.)

The gradient has the numerical value of −16 000.

What is the activation energy, in kJ mol^{-1}, for this reaction?

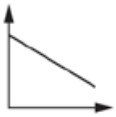
A +1.92
B +133
C +1920
D +133 000

Your answer ☐ **[1]**

4. A reaction is zero order with respect to a reactant.

Which rate-concentration graph for the reactant is the correct shape?

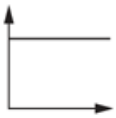
A



B

C

D



Your answer ☐ **[1]**

5. A student investigates the rate of a reaction that is 1st order with respect to hydrochloric acid, HC*l*(aq).

- The student carries out a reaction using 0.680 mol dm^{-3} HC*l*(aq). The initial rate is 9.52×10^{-4} mol dm^{-3} s^{-1}.
- The student dilutes a different sample of 0.680 mol dm^{-3} HC*l* (aq) with water. The pH of this diluted acid is 1.50.
- The student repeats the reaction using the same volume of this diluted acid.

Determine the initial rate using this diluted acid.

initial rate = ... mol dm^{-3} s^{-1} **[3]**

6. The half-life for a first order reaction is 80 s.
What is the rate constant *k*, in s^{-1}, for this reaction?

A 8.66×10^{-3}
B 0.0125
C 55.5
D 115

Your answer ☐ **[1]**

7(a). A catalytic converter in a car removes nitrogen monoxide, NO, and carbon monoxide, CO, from the exhaust gases.

One reaction that happens in a catalytic converter is shown below.

$2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)$ **Reaction 16.1**

i. Explain how increasing the temperature increases the rate of **Reaction 16.1**.

Include a labelled sketch, using Boltzmann distributions, on the grid below.

Label the axes.

[3]

ii. The rate of **Reaction 16.1** is investigated by carrying out three experiments at the same temperature. The results are shown below.

Experiment	[NO(g)]/moldm^{-3}	[CO(g)]/moldm^{-3}	Initial rate/moldm^{-3} s^{-1}
1	2.75×10^{-4}	7.25×10^{-4}	1.85×10^{-4}
2	5.50×10^{-4}	7.25×10^{-4}	7.40×10^{-4}
3	1.10×10^{-3}	2.90×10^{-3}	1.18×10^{-2}

Determine the orders with respect to NO and CO, the rate equation, and the rate constant, *k*, including units.

Explain your reasoning.

k = ... units ..... **[5]**

(b). Carbon monoxide reacts with nitrogen dioxide as shown in **Reaction 16.2**.

$CO(g) + NO_2(g) \rightarrow NO(g) + CO_2(g)$ **Reaction 16.2**

The rate equation for **Reaction 16.2** is shown below:

rate = $k[NO_2(g)]^2$

Suggest a possible two-step mechanism for **Reaction 16.2**.

The first step is much slower than the second step.

step 1 _____

step 2 _____

[2]

8. Two students plan to investigate **Equilibrium 4.1**, shown below.

$CoCl_4^{2-}(aq) + 6H_2O(l) \rightleftharpoons [Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq)$ **Equilibrium 4.1**

blue pink

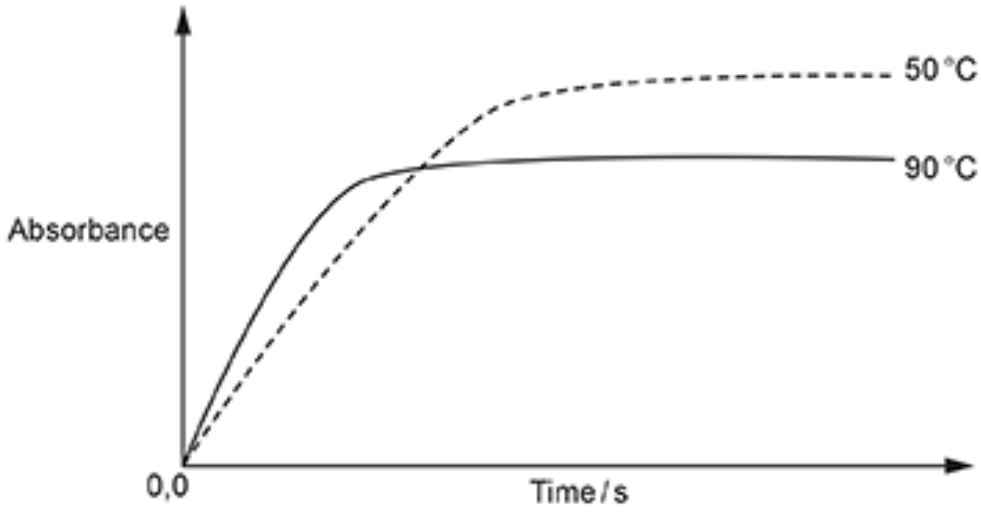
The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- One student heats 20 cm^3 of the mixture to 50°C.
- The other student heats 20 cm^3 of the mixture to 90°C.

The students use colorimetry to observe how the colour of the equilibrium mixture changes over time.

- The colorimeter is set up so that the greater the absorbance, the greater the concentration of $[Co(H_2O)_6]^{2+}$.
- The initial absorbance is set to zero.
- The absorbance is recorded every 30 seconds.

The students plot the graph below from the results of the experiment.



Use the graph and relevant chemical theory to answer the following. Include all reasoning:

- Explain the different initial rates at 50°C and 90°C.
- Predict the sign of Δ*H* for the forward reaction in **Equilibrium 4.1**.

[4]

END OF QUESTION PAPER