Reaction Kinetics

Question Paper 2

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	Reaction Kinetics
Sub-Topic	
Paper Type	Theory
Booklet	Question Paper 2

Time Allowed: **63 minutes**

Score: **/52**

Percentage: **/100**

Grade Boundaries:

A*	A	B	C	D	E	U
>85%	777.5%	70%	62.5%	57.5%	45%	<45%

1 Carbon monoxide, CO, occurs in the exhaust gases of internal combustion engines.

(a) Suggest a dot-and-cross diagram for CO.

(ii) Suggest **one** reason why CO is produced in addition to CO_2 in some internal combustion engines.

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(iii) Carbon monoxide can be removed from the exhaust gases by a catalytic converter. Write an equation for a reaction that occurs in a catalytic converter that removes CO.

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[3]

(b) The standard enthalpy change of formation, $\Delta H_f^\ominus$, of CO is –111 kJ mol^{-1}, and that of CO_2 is –394 kJ mol^{-1}.
Calculate the standard enthalpy change of the following reaction.

$$C(s) + CO_2(g) \rightarrow 2CO(g)$$

$\Delta H^\ominus$ = ... kJ mol^{-1}
[2]

(c) Carbon monoxide reacts with a ruthenium(II) chloride complex according to the equation

$$[Ru(H_2O)_2Cl_4]^{2-} + CO \rightarrow [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O.$$

(i) Describe the *type of reaction* that is occurring here.

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(ii) During the reaction, the colour of the solution changes from deep blue to green. Explain the origin of colour in transition element complexes, and why different complexes often have different colours.

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The following table shows how the initial rate of this reaction varies with different concentrations of reactants.

$[[Ru(H_2O)_2Cl_4]^{2-}]$ / mol dm^{-3}	[CO] / mol dm^{-3}	rate / mol dm^{-3} s^{-1}
1.1×10^{-2}	1.7×10^{-3}	1.6×10^{-7}
1.6×10^{-2}	3.6×10^{-3}	2.3×10^{-7}
2.2×10^{-2}	2.7×10^{-3}	3.2×10^{-7}

(iii) Use these data to determine the order of reaction with respect to each reagent, and write the rate equation for the reaction.

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There are three possible mechanisms for this reaction, which are described below.

mechanism 1 $[Ru(H_2O)_2Cl_4]^{2-} + CO \xrightarrow{\text{slow}} [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O$

mechanism 2 $[Ru(H_2O)_2Cl_4]^{2-} \xrightarrow{\text{slow}} [Ru(H_2O)Cl_4]^{2-} + H_2O$

$[Ru(H_2O)Cl_4]^{2-} + CO \xrightarrow{\text{fast}} [Ru(H_2O)(CO)Cl_4]^{2-}$

mechanism 3 $[Ru(H_2O)_2Cl_4]^{2-} + CO \xrightarrow{\text{slow}} [Ru(H_2O)_2(CO)Cl_4]^{2-}$

$[Ru(H_2O)_2(CO)Cl_4]^{2-} \xrightarrow{\text{fast}} [Ru(H_2O)(CO)Cl_4]^{2-} + H_2O$

(iv) Deduce which of these three mechanisms is consistent with the rate equation you suggested in part **(iii)**. Explain your answer.

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....

[10]

[Total: 15]

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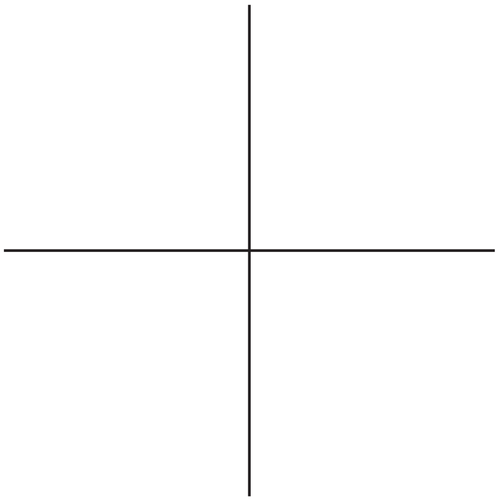
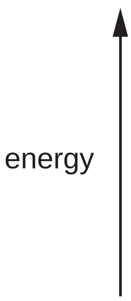
2 **(a)** On the following diagram draw a clear **labelled** sketch to describe the shape and symmetry of a typical d-orbital.



[2]

(b) Although the five d-orbitals are at the same energy in an isolated atom, when a transition element ion is in an octahedral complex the orbitals are split into two groups.

(i) Draw an orbital energy diagram to show this, indicating the number of orbitals in each group.



(ii) Use your diagram as an aid in explaining the following.

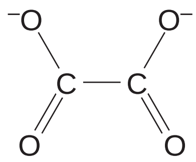
- Transition element complexes are often coloured.

- The colour of a complex of a given transition element often changes when the ligands around it are changed.

[7]

(c) Heating a solution containing potassium ethanedioate, iron(II) ethanedioate and hydrogen peroxide produces the light green complex $K_3Fe(C_2O_4)_3$, which contains the ion $[Fe(C_2O_4)_3]^{3-}$.

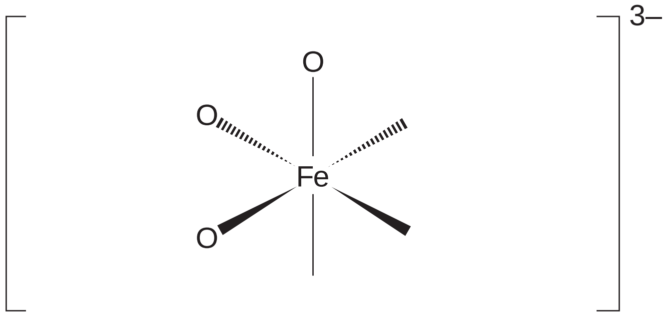
The structure of the ethanedioate ion is as follows.



(i) Calculate the oxidation number of carbon in this ion. ....

(ii) Calculate the oxidation number of iron in $[Fe(C_2O_4)_3]^{3-}$. ....

(iii) The iron atom in the $[Fe(C_2O_4)_3]^{3-}$ ion is surrounded octahedrally by six oxygen atoms. Complete the following **displayed** formula of this ion.



(iv) In sunlight the complex decomposes into potassium ethanedioate, iron(II) ethanedioate and carbon dioxide.

Use oxidation numbers to help you balance the following equation for this decomposition.

$K_3Fe(C_2O_4)_3 \rightarrow$ ....$K_2C_2O_4$ + ...FeC_2O_4 + ...CO_2

[5]

[Total: 14]

3 **(a)** **(i)** What is meant by the term *ligand* as applied to the chemistry of the transition elements?

....

(ii) Describe the type of bonding that occurs between a ligand and a transition element.

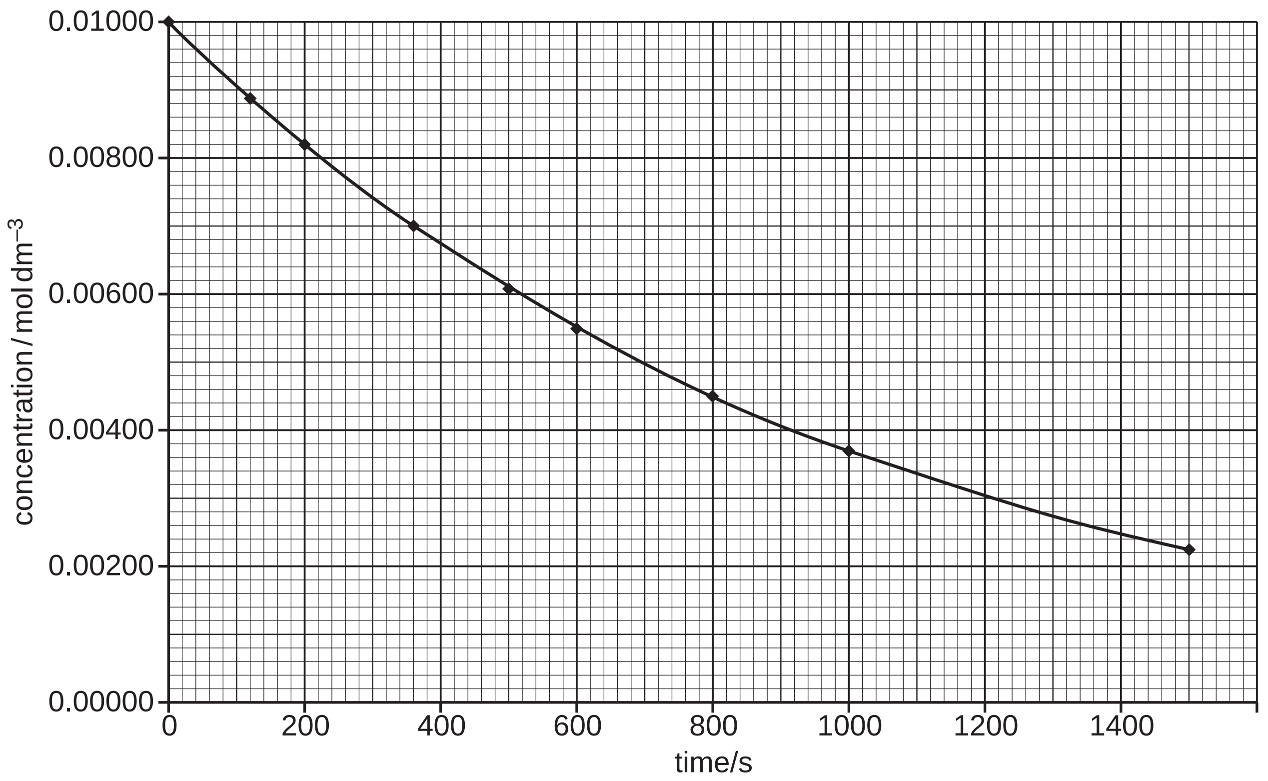
....

[2]

(b) Chromium hexacarbonyl undergoes the following ligand replacement reaction.

$$Cr(CO)_6 + PR_3 \longrightarrow Cr(CO)_5PR_3 + CO$$

Two separate experiments were carried out to study the rate of this reaction.
In the first experiment, the ligand PR_3 was in a large excess and $[Cr(CO)_6]$ was measured with time. The results are shown on the graph below.



In the second experiment, $Cr(CO)_6$ was in a large excess, and $[PR_3]$ was measured with time. The following results were obtained.

time / s	$[PR_3]$ / mol dm^{-3}
0	0.0100
120	0.0076
200	0.0060
360	0.0028

(i) Plot the data in the table on the graph above, using the same axis scales, and draw the best-fit line through your points.

(ii) Use the graphs to determine the order of reaction with respect to $Cr(CO)_6$ and PR_3. In each case explain how you arrived at your answer.

$Cr(CO)_6$

....

....

PR_3

....

....

(iii) Write the rate equation for the reaction, and calculate a value for the rate constant, using the method of initial rates, or any other method you prefer.

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(iv) State the units of the rate constant.

....

(v) Four possible mechanisms for this reaction are given below. Draw a **circle** around the letter next to the **one** mechanism which is consistent with the rate equation you have written in **(iii)**.

A $Cr(CO)_6 \rightarrow Cr(CO)_5 + CO$ fast
$Cr(CO)_5 + PR_3 \rightarrow Cr(CO)_5PR_3$ slow

B $Cr(CO)_6 \rightarrow Cr(CO)_5 + CO$ slow
$Cr(CO)_5 + PR_3 \rightarrow Cr(CO)_5PR_3$ fast

C $Cr(CO)_6 + PR_3 \rightarrow [OC\text{---}Cr(CO)_4\text{---}PR_3] \rightarrow Cr(CO)_5PR_3 + CO$
(transition state)

D $Cr(CO)_6 + PR_3 \rightarrow Cr(CO)_6PR_3$ slow
$Cr(CO)_6PR_3 \rightarrow Cr(CO)_5PR_3 + CO$ fast

Explain your answer.

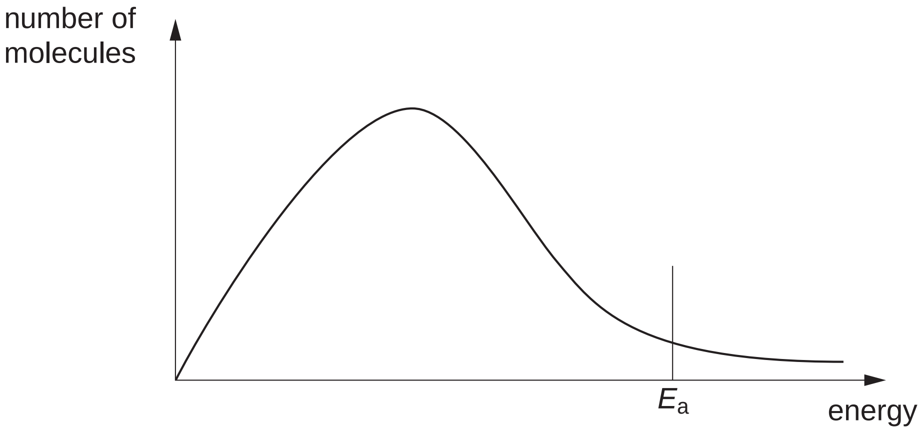
....

....

[9]

[Total: 11]

4 The diagram below shows, for a given temperature T, a Boltzmann distribution of the kinetic energy of the molecules of a mixture of two gases that will react together, such as nitrogen and hydrogen.
The activation energy for the reaction, E_a, is marked.



(a) **On the graph above,**

(i) draw a new distribution curve, **clearly labelled T′**, for the same mixture of gases at a higher temperature, **T′**;

(ii) **mark clearly, as H**, the position of the activation energy of the reaction at the higher temperature, **T′**.

[3]

(b) Explain the meaning of the term *activation energy*.

....

....

....

.... [2]

The reaction between nitrogen and hydrogen to produce ammonia in the Haber process is an example of a large-scale gaseous reaction that is catalysed.

(c) **(i)** State the catalyst used and give the operating temperature and pressure of the Haber process.

catalyst ....

temperature ....

pressure ....

(ii) **On the energy axis of the graph opposite**, mark the position, **clearly labelled C**, of the activation energy of the reaction when a catalyst is used.

(iii) Use your answer to **(ii)** to explain how the use of a catalyst results in reactions occurring at a faster rate.

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....

....
[3]

(d) Two reactions involving aqueous NaOH are given below.

$CH_3CHBrCH_3$ + Na $\longrightarrow$ $CH_3CH(OH)CH_3$ + NaBr **reaction 1**

HCl + NaOH $\longrightarrow$ NaCl + H_2O **reaction 2**

In order for **reaction 1** to occur, the reagents must be heated together for some time. On the other hand, **reaction 2** is almost instantaneous at room temperature.

Suggest brief explanations why the rates of these two reactions are very different.

reaction 1 ....

....

....

reaction 2 ....

....

.... [4]

[Total: 12]