Anglo-Chinese Junior College

JC2 Preliminary Examinations
Higher 2

| CANDIDATE NAME | | FORM CLASS | |
| TUTORIAL CLASS | | INDEX NUMBER | |

CHEMISTRY   **9729/02**
Paper 2 Structured Questions   27 August 2025
     2 hours

Candidates answer on the Question Paper.
Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your index number and name in the spaces at the top of this page.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.
The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiners' use only	
1	/ 7
2	/ 12
3	/ 10
4	/ 11
5	/ 11
6	/ 16
7	/ 8
Total	**/ 75**

This document consists of **24** printed pages.

Answer **all** questions in the spaces provided.

1 When ammonium dichromate(VI) is added gradually to molten ammonium thiocyanate, Reinecke's salt is formed. It has the formula $NH_4[Cr(SCN)_x(NH_3)_y]$ and the following composition by mass: Cr 15.5 %; S 38.15 %; N 29.2 %.

   (a) Calculate the values of x and y in the above formula.

<div style="text-align: right">[2]</div>

   (b) Suggest a shape for the complex anion.

   …………………………………………………………………………………………………...[1]

   (c) Draw two possible structures for the anion and state the type of isomerism it exhibits.

   …………………………………………………………………………………………………...[2]

(d) Linkage isomerism is a form of constitutional isomerism in which certain coordination compounds have the same composition but differ in which atom of the ligand is bonded to the metal.

Examples of linkage isomers are violet-colored $[(NH_3)_5Co\text{-}SCN]^{2+}$ (S being the donor atom) and the orange $[(NH_3)_5Co\text{-}NCS]^{2+}$ (N being the donor atom).

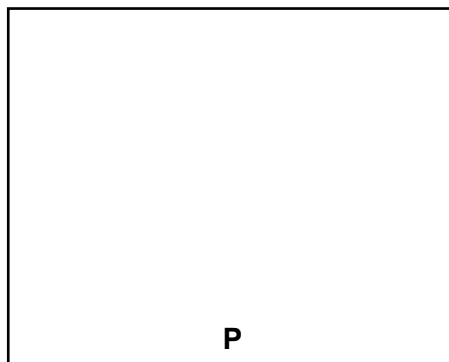Draw the dot-and-cross diagrams of NCS^- and SCN^-. In each diagram, underline the donor atom.

[2]

[Total: 7]

2 (a) X can be converted to **Y** via three steps as shown in the reaction scheme below.

$$X \xrightarrow[\text{UV}]{\text{limiting } Cl_2,} P \longrightarrow Q \longrightarrow Y$$

(i) There are two isomers possible for **P**. Draw the structure of **P** that will eventually lead on to **Y**.

P

[1]

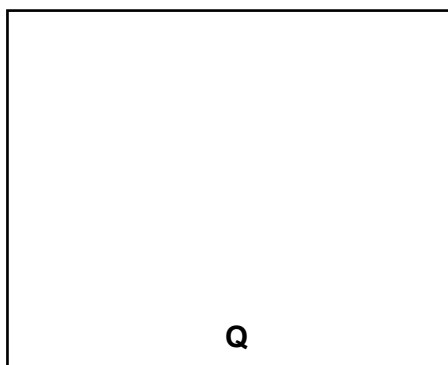**(ii)** Explain if your answer in **(a)(i)** is the major product.

……………………………………………………………………………………………………...

……………………………………………………………………………………………………...

……………………………………………………………………………………………………...

……………………………………………………………………………………………[2]

**(iii)** Draw the structure of **Q**. State the reagents and conditions to synthesise **Q** from **P**.

Q

reagents & conditions ………………………………………………………………………..[2]

(b) **(i)** **G** has the molecular formula, C_8H_{14}. Treating **G** with hydrogen in the presence of Ni, yields **H**, with the molecular formula, C_8H_{16}. Upon mild oxidation, **G** gives a tertiary diol, **J**. Upon vigorous oxidation **G** gives a diketone, **K**, which reacts with aqueous alkaline iodine to produce hexanedioic acid upon acidification.

Draw the structures of **G**, **H**, **J** and **K**.

G	**H**
J	**K**
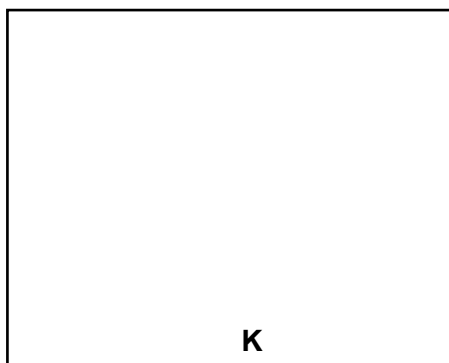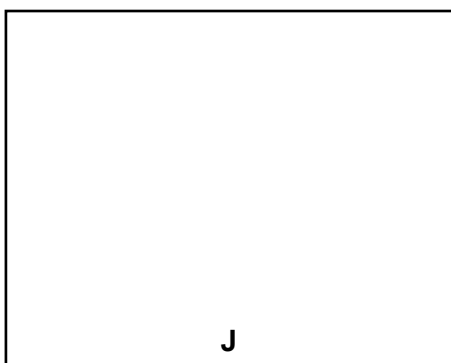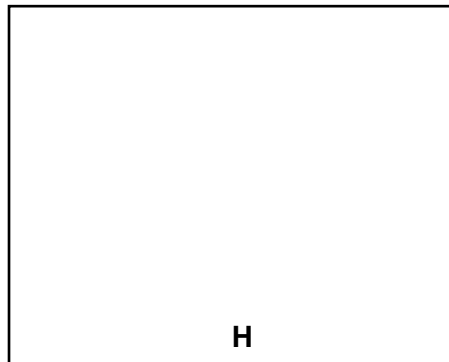
[4]

(ii) **L** is an isomer of **G**. Treating **L** with hydrogen in the presence of Ni, yields **W**, with the molecular formula, C_8H_{18}. It undergoes vigorous oxidation to give propanone as the only organic product in addition to CO_2.

Deduce the structure of **L** with reasoning.

L

....

....

....

....

....

....[3]

[Total: 12]

3 (a) At the time of its discovery by Scottish chemist Sir William Ramsay, the noble gas xenon was considered to be inert. It has since been discovered that xenon will react with strong oxidants. For example, xenon reacts with fluorine gas, forming a series of fluorides, XeF_2, XeF_4 and XeF_6.

(i) The structure of xenon tetrafluoride has six electron pairs on xenon and therefore the structure is based on an octahedral configuration as shown below.
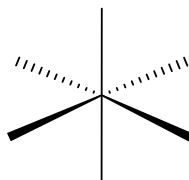
On Fig. 3.1, draw the two possible three-dimensional arrangements of the electron pairs on xenon in xenon tetrafluoride and tick the one observed, that gives the molecule its shape, explaining your choice with appropriate reasoning based on the principles of the VSEPR theory.

Fig. 3.1

……………………………………………………………………………………………...

……………………………………………………………………………………………...

……………………………………………………………………………………………...

………………………………………………………………………………………….[2]

(ii) The structure of xenon difluoride has five electron pairs on xenon and therefore the structure is based on a trigonal bipyramidal configuration as shown below.

On Fig. 3.2, draw the three possible three-dimensional arrangements of the five electron pairs on xenon in xenon difluoride and tick the one observed, that gives the molecule its shape, explaining your choice with appropriate reasoning based on the principles of the VSEPR theory.
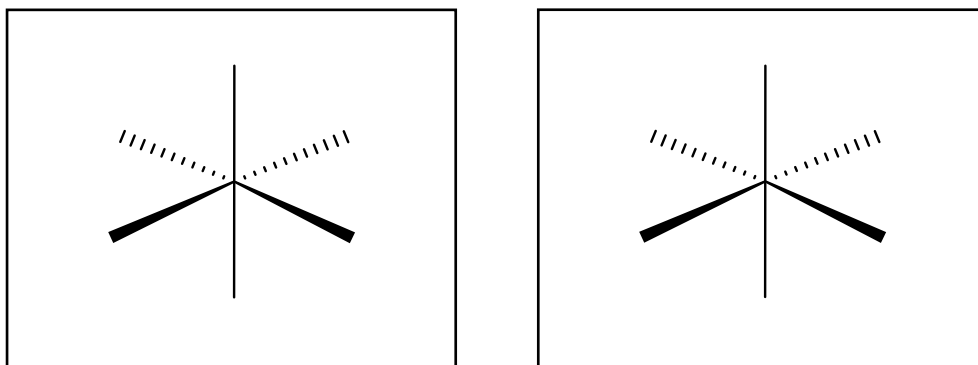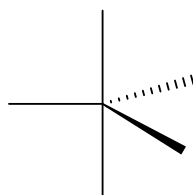

Fig. 3.2

....

....

....

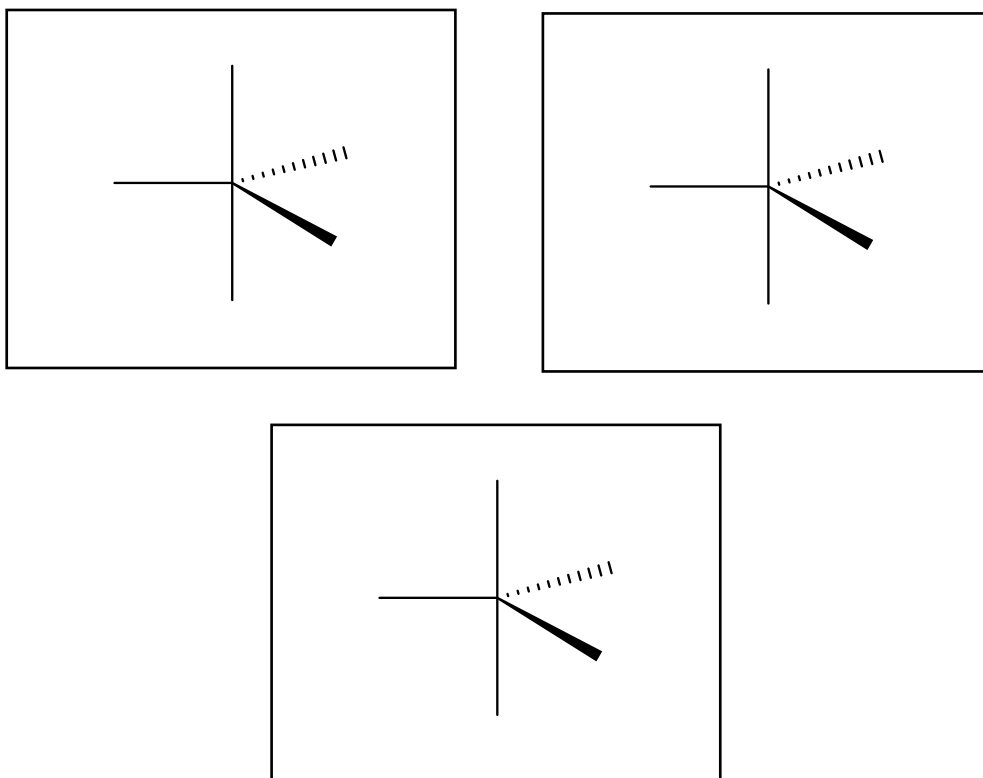...[3]

(b) The kinetics of the formation of xenon difluoride from xenon and fluorine has been studied under various conditions. At 120 °C, the rate equation for the formation of XeF_2 is found to be first order with respect to Xe and zero order with respect to F_2.

    (i) Write the rate equation for the formation of XeF_2 and suggest the units for the rate constant.

[2]

    (ii) The Arrhenius equation describes the relationship between the rate constant and temperature.

$$k = Ae^{-\frac{E_a}{RT}}$$

The uncatalysed reaction between xenon and fluorine to form XeF_2 at a temperature T has a rate constant k, with collision frequency factor A and activation energy, E_a.

When a nickel difluoride catalyst is added to the reaction mixture, the rate constant changes to k_{cat}, with a different collision frequency A_{cat} and a different activation energy, E_{cat}. It is found that the catalysed reaction is 13 times faster at 120 °C and 23 times faster at 100 °C. The change in activation energy, $\Delta E = E_a - E_{cat}$.

Assuming that the collision frequency factors do not depend on temperature, write an expression for the ratio k_{cat}/k in terms of T, ΔE and any constants.

[1]

(iii) Hence, using the ratio in **(b)(ii)** and the information given below, calculate the change in activation energy, ΔE, in kJ mol^{-1}, when the temperature increased from 373 K to 393 K. Given that $\dfrac{k_{cat}(393\text{ K})}{k(393\text{ K})} = 13$ and $\dfrac{k_{cat}(373\text{ K})}{k(373\text{ K})} = 23$.

[2]

[Total: 10]

4 (a) Ethanol is dissolved in blood and distributed to organs in the body. As a volatile compound, ethanol can be vaporised quite easily. In the lungs, ethanol can change its phase from liquid to gaseous and it can be exhaled with air. Since the concentration of alcohol vapor in lungs is directly related to its concentration in blood, blood alcohol concentration can be measured using a device called a breathalyser.

In one of the older versions of breathalyser, a suspect breathes into the device and exhaled air is allowed to pass through a solution of potassium dichromate which oxidises ethanol to acetic acid. This oxidation is accompanied by a colour change from orange to green and a detector records the change in colour intensity, which is used to calculate the percentage of alcohol in breath. When the oxidation of alcohol by potassium dichromate is carried out in an electrochemical cell, either the electrical current generated by this reaction or the change in the electromotive force can be measured and used for the estimation of alcohol content of blood.

(i) Write a balanced ionic equation for the oxidation of ethanol by the dichromate ion in acidic solution.

[2]

(ii) If the standard potential for the reduction of $Cr_2O_7^{2-}$ to Cr^{3+} is 1.330 V and that for the reduction of ethanoic acid to ethanol is 0.058 V, calculate the standard electromotive force, $E^{\ominus}$, for the overall reaction.

[1]

(iii) When a suspect breathes into a breathalyser which is designed as an electrochemical cell, the oxidation of the ethanol generates a current of 0.10 A for 60 s.

Calculate the mass of alcohol in the exhaled breath.

[3]

(iv) In calculating the alcohol content in blood from the mass of alcohol in a breath, the "2100:1 partition ratio" needs to be considered. The ratio states that each milliliter of blood has 2100 times the mass of ethanol as each milliliter of expired air.

If the volume of expired air described in **(a)(iii)** is 60.0 cm^3, calculate the mass of alcohol per cm^3 of blood.

[1]

(b) The value of the solubility product is related to the Gibbs free energy change, $\Delta G^{\ominus}$, in $J\ mol^{-1}$, by the mathematical expression given below.

$$K_{sp} = 10^{-\left(\frac{\Delta G^{\ominus}}{2.3RT}\right)}$$

Using the expression above and the cycle in Fig. 4.1 that involves the standard reduction potentials in Table 4.1, calculate the numerical value of the solubility product, K_{sp}, of AgCN at 25 °C.

Table 4.1

	$E^{\ominus}$ / V
$AgCN(s) + e \rightleftharpoons Ag(s) + CN^-(aq)$	−0.01
$Ag^+(aq) + e \rightleftharpoons Ag(s)$	+0.80

$$AgCN(s) \rightleftharpoons Ag^+(aq) + CN^-(aq)$$

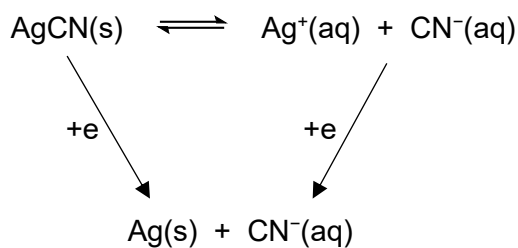+e   +e

$$Ag(s) + CN^-(aq)$$

Fig. 4.1

[4]

[Total: 11]

5 The Haber process is used to make ammonia, the main use of which is in fertilisers that are often sprayed on crops. Around 1% of the entire global energy supply is used in the Haber process and so research groups are looking to find more sustainable methods of producing ammonia.

One recently published approach to making ammonia uses the following three-step method.

Step 1 Electrolysis of molten lithium hydroxide at 750 K to form lithium metal.

$$4LiOH \longrightarrow 4Li + 2H_2O + O_2$$

Step 2 Reaction of lithium metal with nitrogen to form lithium nitride.

Step 3 Reaction of lithium nitride with water to re-form lithium hydroxide and ammonia.

Thus, the lithium hydroxide formed in Step 3 can be re-used in Step 1 and the process can be repeated.

The relevant thermochemical data are provided in Table 5.1.

Table 5.1

At 750 K	LiOH	Li	H_2O	O_2
ΔH_f / kJ mol^{-1}	−446.0	+15.0	−268.0	+15.8
ΔS_r for step 1 at 750 K is +427 J K^{-1} mol^{-1}				

(a) Explain why the enthalpy changes of formation of the elements Li and O_2 are not zero at 750 K.

……………………………………………………………………………………………..................

……………………………………………………………………………………………..................

…………………………………………………………………………………………………..[1]

(b) Calculate ΔH_r and hence ΔG_r for Step 1 at 750 K.

[2]

(c) Given that the electrolysis will only proceed at an appreciable rate when the applied potential exceeds the electrochemical cell potential by 0.60 V, calculate the minimum potential that should be applied in Step 1.

[1]

(d) Write the chemical equations for Step 2 and Step 3. Hence calculate the stoichiometric ratio between the lithium produced in Step 1 and the ammonia produced in Step 3.

[2]

(e) In a small-scale experiment, the researchers applied a current of 0.200 A for 1000 seconds. The yield of lithium production in this process was 88.5% in Step 1. The yield of Steps 2 and 3 can be assumed to be 100%.

Calculate the mass of lithium generated in Step 1.

[2]

(f) Calculate the volume of ammonia produced, in cm^3, at room temperature and pressure.

[1]

(g) A potential application of this approach is to use renewable energy sources as the source of electricity for the electrolysis and to produce ammonia at a farm where it can be used straight away. The average size of a UK farm is 130 acres, and a farm requires 0.0770 tonnes of ammonia per acre annually.

If the lithium hydroxide was not recycled at the end of the process, calculate the total mass of lithium, in tonnes, that would have to be produced to generate the required mass of ammonia for a year. [1 tonne = 1000 kg]

[2]

[Total: 11]

6 **(a)** Propanone can exist in *keto* and *enol* forms.

keto form of propanone   enol form of propanone
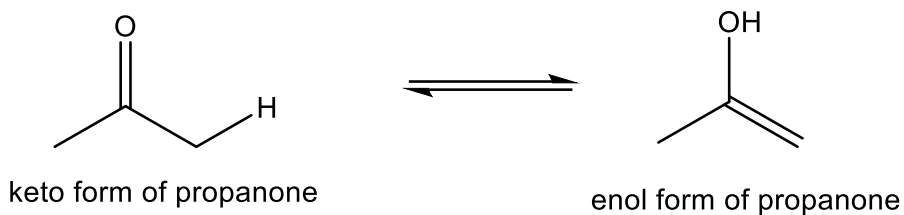
The enol form is derived from the keto form by transferring a hydrogen atom to the oxygen atom.

At room temperature and pressure, the keto form is the predominant form at equilibrium suggesting that the keto form is the more stable form.

Using bond energy data from the *Data Booklet*, calculate the enthalpy change for the above interconversion, and hence explain why the equilibrium lies heavily towards the keto form.

[2]

(b) The conversion of keto form to the enol form of propanone can be catalysed by an acid.

The first equilibrium step of the mechanism involves protonation of oxygen atom of the C=O bond as given below.
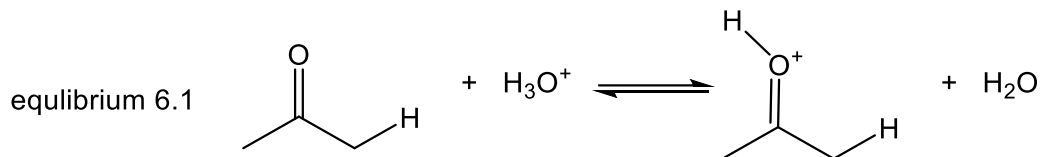
equlibrium 6.1

The K_c expression for equilibrium 6.1 is given as follows.

(i) Write the K_a expressions for the acid dissociation of H_3O^+ and $(CH_3)_2C=OH^+$ using their respective equilibrium equations given below.

$$H_3O^+ \rightleftharpoons H_2O + H^+$$
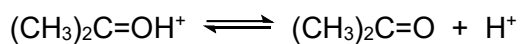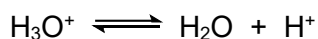
$$(CH_3)_2C=OH^+ \rightleftharpoons (CH_3)_2C=O + H^+$$

[2]

(ii) Hence, express K_c for equilibrium 6.1 in terms of the two K_a expressions in **(b)(i)**.

[1]

(iii) Given that the pK_a of H_3O^+ is -1.7 and the pK_a of $(CH_3)_2C=OH^+$ is -7.2, calculate a value of K_c for equilibrium 6.1.

[1]

(iv) Given that $\Delta G^{\ominus} = -RT \ln K$, calculate the Gibbs Free energy change, in kJ mol^{-1}, for equilibrium 6.1.

[2]

(v) Based on your answers to the values of K_c and $\Delta G^{\ominus}$, comment on the relative stability of the keto form versus the enol form.

....

....

....

....

....

....[2]

(vi) Tautomerisation is a type of isomerisation where two molecules with the same molecular formula but different connectivity (constitutional isomers) rapidly interconvert in a solution or equilibrium. The most well-known example is the interconversion between a keto (containing a carbonyl group) and an enol (containing an alcohol and a double bond) form of a molecule.

Outline the mechanism for the tautomerisation of propanone to its enol form catalysed by acid, showing all curly arrows, lone pairs and charges.

[3]

(c) The enol form of pentane-2,4-dione is unusually stable and hence the equilibrium lies more towards the enol form.

keto form of pentane-2,4-dione   enol form of pentane-2,4-dione
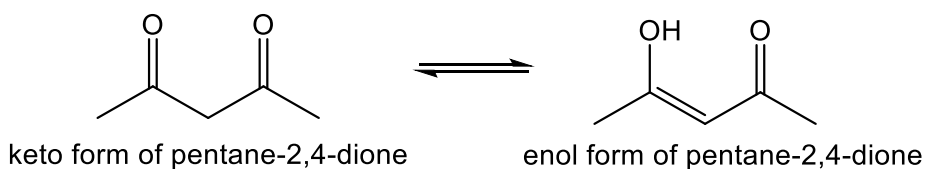
It is also observed that the percentage of the enol form increases as the solvent used is changed from a polar solvent to a non-polar solvent.

(i) By comparing the structures of the enol form with the keto form, suggest a reason for the increased stability of the enol form in pentane-2,4-dione.

....

....[1]

(ii) Explain why the keto form is favoured with polar solvents.

....

....

....

....[1]

(iii) Another enol form of pentane-2,4-dione, as shown below can also be drawn.
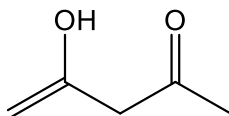
another enol form of pentane-2,4-dione

Explain if this enol form is likely to be formed as well.

…………………………………………………………………………………………...

………………………………………………………………………………….[1]

[Total: 16]

7 (a) Solid magnesium hydroxide decomposes when heated to form two products. One of the products formed is steam.

(i) Construct a balanced equation, with state symbols, for the above reaction.

………………………………………………………………………………………..[1]

(ii) The variation in thermal stability of Group 2 hydroxides is similar to that of Group 2 carbonates.

Explain whether magnesium hydroxide is more or less thermally stable than barium hydroxide.

………………………………………………………………………………………......

…………………………………………………………………………………………....

…………………………………………………………………………………………....

…………………………………………………………………………………………....

…………………………………………………………………………………………....

………………………………………………………………………………………….....

………………………………………………………………………………………….....

…………………………………………………………………………………………..[3]

(b) **(i)** Using relevant data from the *Data Booklet*, comment on the thermal stability of hydrogen bromide and hydrogen iodide.

……………………………………………………………………………………….....

……………………………………………………………………………………….....

………………………………………………………………………………………….[1]

(ii) Identify a transition metal cation that can be used to differentiate the oxidising strengths of Br_2 and I_2. Explain your answer with appropriate workings.

[3]

[Total: 8]

24

Additional answer space

If you use the following page to complete the answer to any question, the question number must be clearly shown.

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………