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TEMASEK JUNIOR COLLEGE
2021 JC2 PRELIMINARY EXAMINATION
Higher 2

TEMASEK
JUNIOR COLLEGE

CHEMISTRY

9729/01

15 September 2021
1 hour

Additional Materials: Multiple Choice Answer Sheet (OMS)
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Write your name, Class and index number on the Answer Sheet in the spaces provided.

1. **Enter your NAME (as in NRIC).** ______________________
2. **Enter the SUBJECT TITLE.** ______________________
3. **Enter the TEST NAME.** ______________________
4. **Enter the CLASS.** ______________________

Write your **name** and **Civics Group**

Write and shade your index number

	WRITE	SHADE APPROPRIATE BOXES
INDEX NUMBER		0 ▭ 1 ▭ 2 ▭ 3 ▭ 4 ▭ 5 ▭ 6 ▭ 7 ▭ 8 ▭ 9 ▭
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		A ▭ B ▭ C ▭ D ▭ E ▭ F ▭ G ▭ H ▭ I ▭

There are **thirty** questions on this paper. Answer **all** questions. For each question there are four possible answers **A**, **B**, **C** and **D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

Read the instructions on the Answer Sheet very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

This document consists of 15 printed pages and 1 blank page.

1 One diatomic molecule of an element **E** has an average mass of 1.18 x 10^{-22} g. **E** reacts with ethene to form C_2H_4**E**$_2$. How many **E** atoms are there in 49.5 g of $C_2H_4E_2$?

A 1.75 x 10^{23}

B 3.01 x 10^{23}

C 3.50 x 10^{23}

D 6.02 x 10^{23}

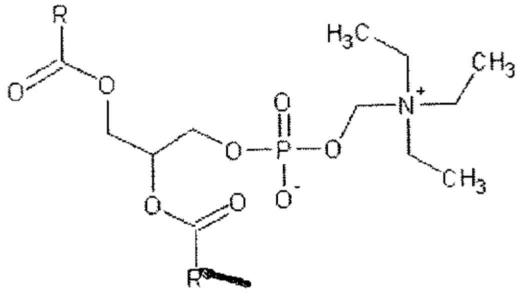
2 The radioactive isotope $^{223}_{88}Ra$ decays to give an element **Q** and emits a high energy α-particle (which is a helium nucleus, $^{4}_{2}He$). No other particle is produced.

$$^{223}_{88}Ra \longrightarrow \mathbf{Q} + ^{4}_{2}He$$

How many neutrons are present in element **Q**?

A 219 **B** 135 **C** 133 **D** 86

3 Lecithin is an emulsifier added to chocolate to help bind the cocoa solids, sugar and milk so they stick to the cocoa butter. Its structure is shown below.



R: long hydrophobic carbon chains

Which of the following statements about lecithin is correct?

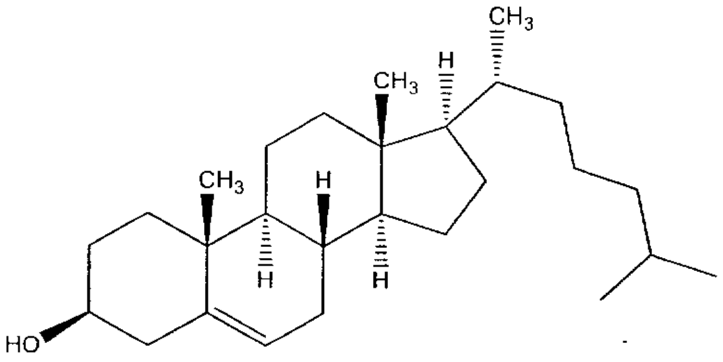
A It can form instantaneous dipole-induced dipole interactions with non-polar molecules present in chocolate.

B It can form hydrogen bonds between its own molecules.

C All bond angles surrounding each carbon atom are 109.5°.

D It does not contain delocalised electrons.

4 Cholesterol is a waxy substance that is present in blood plasma and in all animal tissues.



Cholesterol

Which of the following statements about cholesterol are **incorrect**?

1 All the seventeen carbon atoms in the four rings lie in the same plane.

2 It can exhibit cis–trans isomerism at the C=C double bond.

3 It is acidic.

A 1 only

B 1 and 2 only

C 2 and 3 only

D 1, 2 and 3

5 A sample of an organic compound of molar mass M is vapourised in a gas syringe and occupies V cm^3 at T K and p Pa.

What is the density of the compound?

A $\dfrac{p \times M \times 273}{T \times 10^5 \times 22700}$

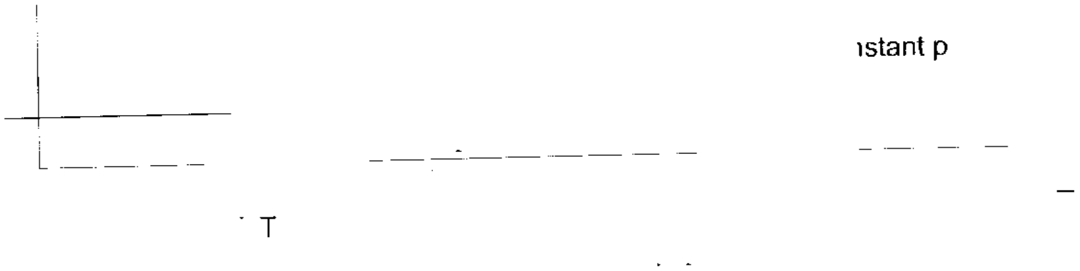
B $\dfrac{p \times M \times 293}{T \times 10^5 \times 24000}$

C $\dfrac{p \times M \times 10^5 \times 22700}{T \times 273}$

D $\dfrac{p \times M \times 273}{T \times 22700}$

[Turn Over

Which graphs correctly describe the behaviour of a fixed mass of an ideal gas (where measured in K)?



C ıd 3 only

X is a Period 3 chloride.

When a few drops of water are added to **X**, steamy white fumes are evolved and a colou liquid is produced.

Which compound is **X**?

C Ↄl_4

X and **Y** are two elements in Period 3 of the Periodic Table. They combine to form comp **Z**. Both **X** and **Y** form oxides that react with aqueous sodium hydroxide. The oxidation nu of **X** in its oxide is +4.

What is the formula of compound **Z**?

C P_4

9 The solids, sodium chloride and sodium iodide, both react with concentrated sulfuric acid at room temperature.

With $NaCl$, the products are $NaHSO_4$ and HCl.

With NaI, the products are $NaHSO_4$, HI, I_2, SO_2, H_2O, S and H_2S.

Which of the following is the best explanation for this difference in products?

A Chloride will displace iodine from solution.

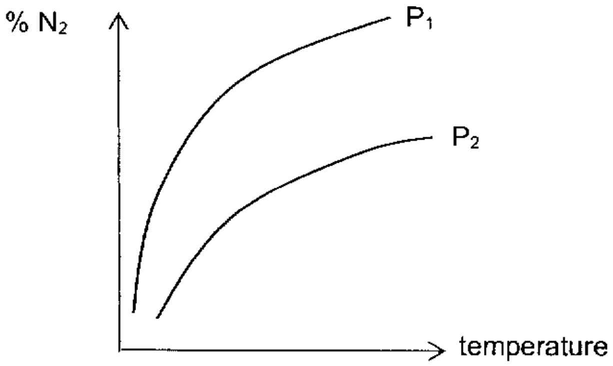
B Iodine is a better oxidising agent than chlorine.

C Iodide is a better reducing agent than chloride.

D Sulfuric acid is able to act as a dehydrating agent with NaI.

10 The graph below shows how the percentage of $N_2(g)$ in the equilibrium mixture of the Haber process varies with temperature at different pressures, P_1 and P_2.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H_r$$



Which row in the table is correct?

	ΔH_r	Pressure
A	positive	$P_1 > P_2$
B	positive	$P_1 < P_2$
C	negative	$P_1 > P_2$
D	negative	$P_1 < P_2$

11 The position of equilibrium lies to the right in each of these reactions.

Reaction 1: $N_2H_4 + HClO \rightleftharpoons N_2H_5^+ + ClO^-$

Reaction 2: $N_2H_5^+ + NH_3 \rightleftharpoons NH_4^+ + N_2H_4$

Based on this information, which statements are correct?

1 ClO^- is the conjugate base of $HClO$.

2 $N_2H_5^+$ is the Bronsted base in Reaction 2.

3 The order of acid strength is $HClO > N_2H_5^+ > NH_4^+$.

4 N_2H_4 is the Lewis acid in Reaction 1.

A 1 and 3 only **B** 1 and 4 only **C** 2 and 3 only **D** 2 and 4 only

12 Which of the following solutions does not change its pH significantly when a small amount of base is added?

A 20 cm^3 of 0.10 mol dm^{-3} ethanoic acid mixed with 20 cm^3 of 0.20 mol dm^{-3} aqueous sodium hydroxide.

B 20 cm^3 of 0.10 mol dm^{-3} aqueous ammonia mixed with 30 cm^3 of 0.10 mol dm^{-3} hydrochloric acid.

C 20 cm^3 of 0.10 mol dm^{-3} sodium hydroxide mixed with 20 cm^3 of 0.20 mol dm^{-3} phenylammonium chloride.

D 20 cm^3 0.10 mol dm^{-3} hydrochloric acid mixed with 10 cm^3 0.1 mol dm^{-3} sodium ethanoate solution.

13 A student dissolved 8.4 g of sodium fluoride in 250 g of water.

Given the following thermodynamic data,

Lattice energy of NaF	–918 kJ mol^{-1}
Enthalpy change of hydration of F^-	–457 kJ mol^{-1}
Enthalpy change of hydration of Na^+	–390 kJ mol^{-1}

What would be the initial temperature of the water if the final temperature of the solution is 20.00 °C? Assume that the specific heat capacity of sodium fluoride solution is 4.2 J g^{-1} K^{-1}.

A 6.48 °C **B** 20.01 °C **C** 33.08 °C **D** 33.52 °C

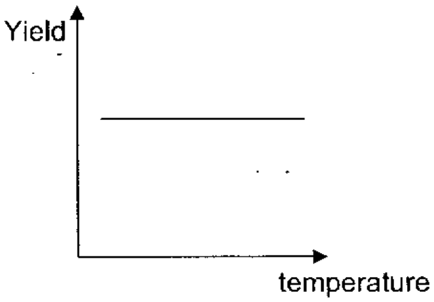
14 In oil refineries, an important process is the recovery of any sulfur from petroleum.

$$2H_2S(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2S(s)$$

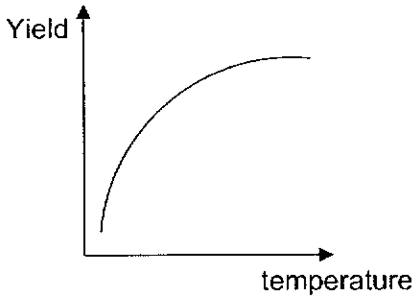
The enthalpy change of formation of $H_2S(g)$ is -20.5 kJ mol^{-1} and that of $H_2O(g)$ is -243.0 kJ mol^{-1}.

Which of the following describes how the yield of sulfur at equilibrium varies as temperature increases?

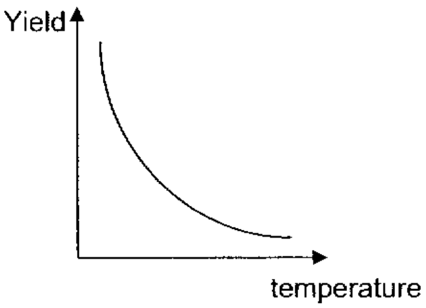
A



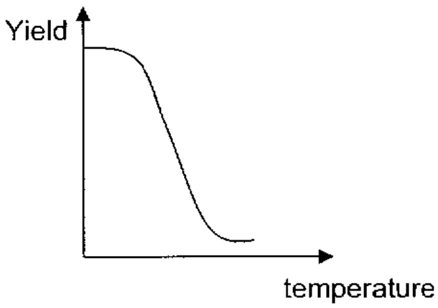
B



C



D



15 Which of the following is true about the value of rate constant of a pseudo first order reaction?

A It depends on the concentration of reactants present in limited amount.

B It depends on the concentration of reactants present in excess amount.

C It is independent of the concentration of reactants.

D It depends only on temperature and presence of catalyst.

16 Consider the following reaction involving aqueous reactants **S** and **T**, and catalysed by **U**:

$$\mathbf{S} + \mathbf{T} \rightarrow \mathbf{V} + \mathbf{W}$$

The solution is originally coloured due to reactant **T**. The kinetics of the above reaction is studied by measuring the time taken for the solution to decolourise. The results are obtained below.

Experiment	Volume of **S** / cm^3	Volume of **T** / cm^3	Volume of **U** / cm^3	Volume of water added / cm^3	Time taken / s
1	10	5	5	5	20
2	5	5	5	10	40
3	10	5	2.5	7.5	40
4	10	2.5	5	7.5	10

What is the rate law for the reaction above?

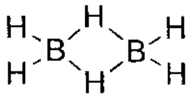
A Rate = k[**S**][**T**][**U**]

B Rate = k[**S**][**T**]

C Rate = k[**T**][**U**]

D Rate = k[**S**][**U**]

17 Diborane, B_2H_6, is a colorless gas with a sweet odour. The structure is unique as it comprises of two bridging hydrogens shared between two boron atoms. The B_2H_2 ring contains two B-H-B bonds, each held together by two electrons.



Diborane

Which of the following statements are correct about diborane?

1 The boron atom is sp^2-hybridised.

2 Only boron is electron deficient.

3 All B-H bonds in diborane have the same bond strength.

A 1 and 3 only

B 1 and 2 only

C 2 and 3 only

D 2 only

18 Colourless liquid **L** with the molecular formula, $C_5H_{11}Cl$, exists as a mixture of two enantiomers. When heated with sodium hydroxide in methanol, a mixture of only two alkenes is formed.

What is structure of **L**?

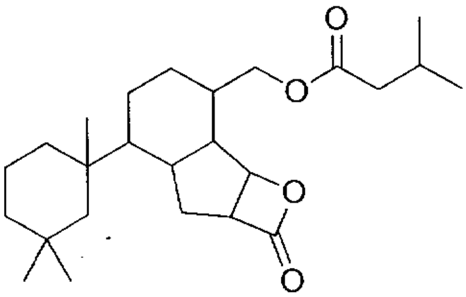
A $(CH_3CH_2)_2CHCl$

B $CH_3CH_2CH_2CHClCH_3$

C $(CH_3)_2CHCHClCH_3$

D $CH_3CH_2CCl(CH_3)_2$

19 The structure of compound **T** is shown below.



compound **T**

How many chiral centers does 1 molecule of **T** have?

A 5 **B** 6 **C** 7 **D** 8

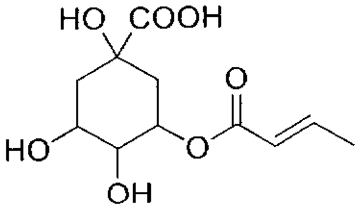
20 When heated with chlorine, 2-methylpentane undergoes substitution. In one of the steps, the free radical, Q•, is formed.

$$\text{2-methylpentane} + Cl\bullet \rightarrow Q\bullet + HCl$$

How many different forms of Q• are theoretically possible?

A 4 **B** 5 **C** 6 **D** 7

21 Compound **X** has the following structure.



Which of the following is **incorrect**?

A When it is heated with acidified potassium manganate(VII), carbon dioxide gas is produced.

B It can react with phenol to form an ester in the presence of concentrated sulfuric acid.

C It can react with up to 2 moles of sodium hydroxide under suitable conditions.

D It reacts with excess sodium metal to produce 2 moles of hydrogen gas.

22 Compound **P** has the following properties.

- It gives white fumes when it is mixed with PCl_5.
- It turns hot acidified potassium dichromate(VI) green.

Which of the following can be **P**?

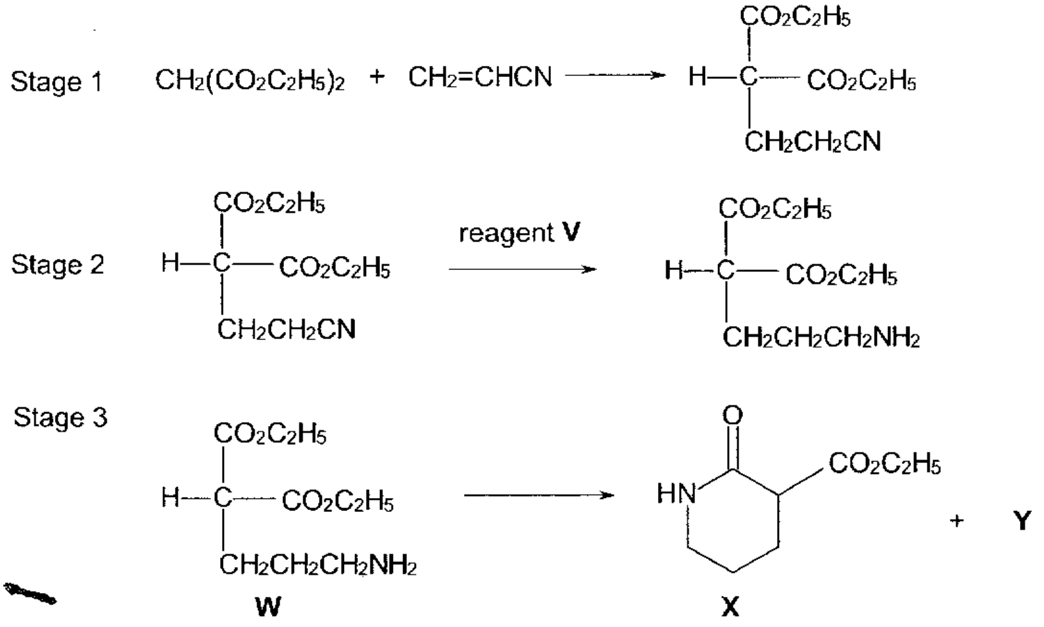
A $(CH_3)_2C(OH)CH_2CH_3$

B $HO_2CCH_2COCH_3$

C $HCOCH_2CH_2OH$

D $CH_3C_6H_4CO_2H$

23 Proline, an amino acid, can be synthesised in the laboratory via a multi-stage synthetic route. Some of the stages are shown below:



Which of the following statements are correct?

1 Stage **1** is an addition reaction.

2 Reagent **V** is lithium aluminum hydride.

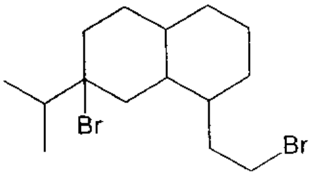
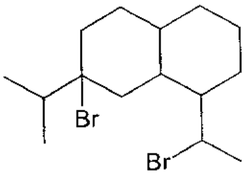
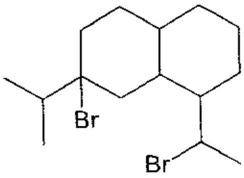
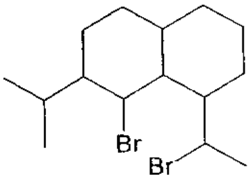
3 **W** reacts with 3 moles of bromoethane and the product formed is more basic than **W**.

4 **Y** gives a yellow precipitate when it is warmed with aqueous alkaline iodine.

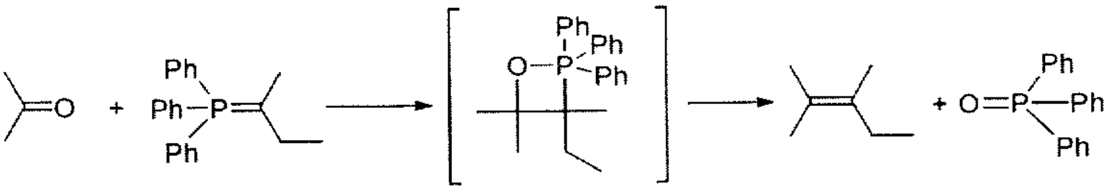
A	1 and 2	**B**	1 and 4	**C**	2 and 3	**D**	3 and 4

24 Compound **P** reacts with HBr to form the major product, **Q**. It further undergoes a reaction in step **2** to form **R**.

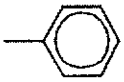
Which row is correct?

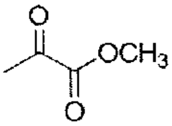
	Structure of **Q**	Reagent and condition for step **2**
A		Alcoholic KCN, heat
B		Alcoholic KCN, heat
C		Excess conc. ammonia in ethanol, heat in sealed tube
D		Excess conc. Ammonia in ethanol, heat in sealed tube

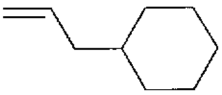
25 The Wittig reaction involves the reaction of a carbonyl compound with a phosphorus ylide to give an alkene. The reaction occurs via an oxaphosphetane intermediate.



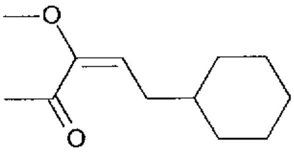
phosphorus ylide oxaphosphetane

(–Ph = )

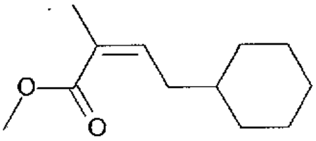
Which of the following is the product formed when 

reacts with (Ph)$_3$P  ?

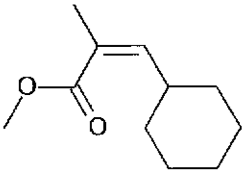
A



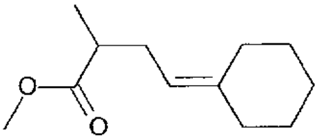
B



C



D



26 Dichloromethane is reacted with excess chlorine in the presence of sunlight.

What could be the products of this reaction?

A $CHCl_3$ and H_2

B $CHCl_3$ and CCl_3CHCl_2

C CCl_4 and CH_2ClCCl_3

D CH_2ClCH_2Cl and HCl

[Turn Over

27 Which set of data shows calcium as a typical s-block element and copper as a typical transition element?

	property	calcium	copper
1	density / g cm^{-3}	1.54	8.92
2	electrical conductivity / relative units	85	9.6
3	melting point / °C	1083	810
4	metallic radius / nm	0.117	0.197

A 1 only

B 1 and 3 only

C 2 and 3 only

D 1, 2, 3 and 4

28 Which of the following statements about the nitration of aromatic compounds are correct?

A Phenol reacts with dilute nitric acid to a pale yellow precipitate.

B The nitration of phenylethanone is faster than ethylbenzene.

C The nitration of phenylethanone requires a lower temperature than phenylamine.

D Phenol requires both concentrated nitric acid and concentrated sulfuric acid to form 2,4,6-trinitrophenol.

29 The lead-acid rechargeable battery has electrodes of solid lead and solid lead(IV) oxide, PbO_2. When the battery discharges, solid lead(II) sulfate, $PbSO_4$ is formed. The electrolyte is an aqueous solution of sulfuric acid.

The two half-equations involved in the electrode reactions are

Electrode X: $PbSO_4(s) + H^+(aq) + 2e^- \rightleftharpoons Pb(s) + HSO_4^-(aq)$ $E^\ominus_1$

Electrode Y: $PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O(l)$ $E^\ominus_2$

Which statement about the discharging process is correct?

A ΔG is positive.

B $E^\ominus_1$ is more positive than $E^\ominus_2$.

C As the cell discharges, the pH decreases.

D For every 2 mole of electrons transferred, 2 mole of $PbSO_4$ is formed.

30 Two separate electrolysis experiments were performed and the volumes of gases produced were measured at the same temperature and pressure.

electrolysis 1	Molten copper(II) chloride was electrolysed for 3 minutes and 10 cm^3 of chlorine was collected.
electrolysis 2	Aqueous sodium hydroxide was electrolysed for 3 minutes and 10 cm^3 of oxygen was collected.

The current used in electrolysis 1 was x.

What was the current used in electrolysis 2?

A $\frac{x}{2}$ **B** x **C** $2x$ **D** $4x$

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2021 TJC JC2 H2 Chemistry
Prelim MCQ Worked Solutions

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
D	C	A	D	A	C	D	B	C	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	C	D	C	B	D	D	C	C	B
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
B	C	B	B	B	B	B	A	D	C

Qn	**Worked Solution**
1.	**Answer: D** M_r of E_2 = $(1.18 \times 10^{-22}) \times (6.02 \times 10^{23})$ = 71.0 M_r $C_2H_4E_2$ = 99.0 Amount of $C_2H_4E_2$ in 49.5 g = (49.5/99.0) = 0.500 mol No. of E atoms in 49.5 g of $C_2H_4E_2$ = $2 \times 0.5 \times 6.02 \times 10^{23} = 6.02 \times 10^{23}$
2.	**Answer: C** $^{223}_{88}Ra \longrightarrow\ ^{219}_{86}\mathbf{Q} +\ ^{4}_{2}He$ Number of neutrons in Q = 219 – 86 = 133
3.	**Answer: A** The long hydrophobic carbon chains on lecithin can form id-id with non-polar molecules. The bond angle with respect to C for –COO group is 120°. It contains delocalized electrons due to the pi bonds.
4.	**Answer: D** Of the seventeenth carbon atoms in the ring, two are sp^2 hybridized while fifteen are sp^3 hybridised. Because these carbon atoms are bonded in a ring, the atoms can't be lying on the same plane (sp^3 hybridization requires electron pairs to be arranged in a tetrahedral configuration). The C=C double bond is found in a ring, For the molecule to exhibit cis-trans isomerism at this double bond requires the ring to be twisted and bond will be broken. So cis-trans isomerism for a C=C double bond found in a ring is not possible. Cholesterol has a secondary alcohol which is non-acidic.
5.	**Answer: A** For gas at stp, PV = nRT

	$1\times10^5 \times 22700 = 1 \times R \times 273$ $R = \frac{10^5\times22700}{273}$ $pV = nRT$, $pV = (mass/M)RT$ Density = mass/V = pM / RT $= \frac{p\times M\times273}{T\times10^5\times22700}$
6.	**Answer: C** $pV = nRT$ Since V and n are constant, $p \propto T$ and $pV \propto T$ (not constant), thus Graph 2 is correct and Graph 1 is incorrect. $PV = nRT$, concentration = n/V, $c = P/R\ (1/T)$. Since pressure is constant, $c \propto 1/T$
7.	**Answer: D** In cold/limited amount of water (or when $PCl_5 : H_2O = 1 : 1$): $PCl_5(s) + H_2O(l) \rightarrow POCl_3(l) + 2HCl(g)$ Colourless liquid White fumes
8.	**Answer: B** Since both **X** and **Y** form oxides that react with aqueous sodium hydroxide, they cannot be SiO_2 (which only react with molten NaOH at high temperature). Oxide of **X** is likely to be SO_2 where S has an oxidation state of +4.
9.	**Answer: C** Iodide ions are better reducing agents since S in $SO_4^{2-}(+6)$ is reduced to $SO_2(+4)$, S(0) and $H_2S(-2)$.
10.	**Answer: D** Keeping pressure constant, when temp increases % of N_2 increases $\Rightarrow$ position of equilibrium shifts left to absorb heat. Backward reaction is endothermic, hence forward reaction is exothermic. Keeping temperature constant, there is an increase in % N_2 when pressure changes from P_2 to P_1. Since equilibrium position shifts left where more gaseous molecules are produced, $P_1 < P_2$.
11.	**Answer: A** Statement 1: $HClO$ is a bronsted acid as it donates a proton. Hence the **product formed (ClO- ion) is a conjugate base.** Statement 2: $N_2H_5^+$ is the Bronsted acid in **Reaction 2 as it donates a proton.** Statement 3: Since the POE lies to the right for both reactions, $HClO$ is a stronger acid than $N_2H_5^+$ from Reaction 1 as it prefers to donate a proton. Likewise for Reaction 2 where $N_2H_5^+$ is a stronger acid than NH_4^+. Statement 4: N_2H_4 is the Lewis base in **Reaction 1** as it donates a lone pair of electrons for dative bonding to a proton from $HClO$.
12.	**Answer: C** Both options A & B have excess sodium hydroxide and HCl respectively after mixing.

Option C forms phenylamine and unreacted phenylammonium chloride after mixing which is an alkaline buffer.

Option D forms CH_3CO_2H and unreacted HCl.

13. **Answer: D**

Enthalpy change of solution = -457 – 390 + 918 kJ mol^{-1} = +71.0 kJ mol^{-1}

Amount of NaF = 8.4/42 mol = 0.200 mol

Heat absorbed by 0.200 mol NaF = 14.2 kJ

$14.2 \times 1000 = mc\Delta T$

$14.2 \times 1000 = 250 \times 4.2 \times (T_{initial} - 20)$

$T_{initial} = 33.52$ °C

14. **Answer: C**

$\Delta H_{reaction} = 2(-243) - 2(-20.5)$ kJ mol^{-1} = -445 kJ mol^{-1}

As T increases, position of equilibrium shifts left, decreasing yield of sulfur(s).

15. **Answer: B**

Consider a pseudo 1st order reaction: rate = $k[A]^1[B]^b$, where B is in excess. So rate = $k'[A]^1$, where $k' = k[B]^b$

Hence, k' depends on temperature (which affect k), conc of B (excess reactant) and presence of catalyst (which affects activation energy).

16. **Answer: D**

Total volume is constant, so vol is proportional to conc of reactants. Relative initial rate of reaction is proportional to (vol of T / time). Hence,

Experiment	Volume of S / cm^3	Volume of T / cm^3	Volume of U / cm^3	Initial rate
1	10	5	5	0.250
2	5	5	5	0.125
3	10	5	2.5	0.125
4	10	2.5	5	0.250

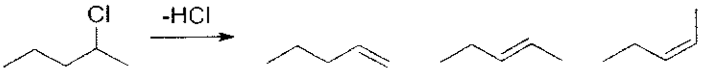
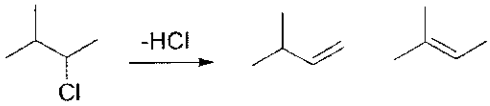
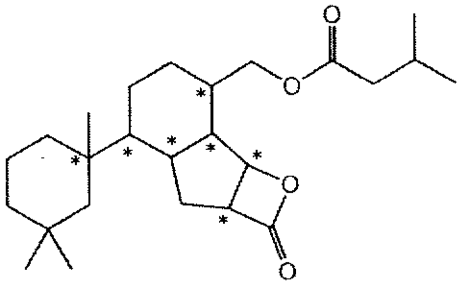
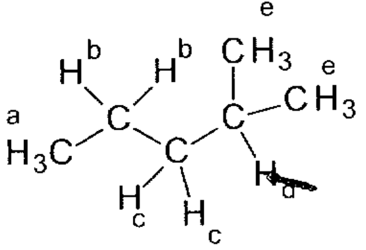
Comparing experiment 1 and 2, when [S] is halved, initial rate is halved too → order wrt [S] = 1

Comparing experiment 1 and 4, when [T] is halved, initial rate is remains constant → order wrt [T] = 0

Comparing experiment 1 and 3, when [U] is halved, initial rate is halved too → order wrt [U] = 1

17. **Answer: D**

Option 1: wrong as there are 4 bond pairs around B atom and should be tetrahedral shape (sp^3 hybridised).

	Option 2: Each boron uses two electrons in bonding to the terminal hydrogen atoms and has one valence electron remaining for additional bonding. The bridging hydrogen atoms provide one electron each. Option 3: Due to 3-center 2-electron bonds, the B-H bond in the ring is a "half-bond" and thus is weaker than the terminal B-H bonds.
18.	**Answer: C** A & D: achiral, so does not exist as enantiomers. B:  C: 
19.	**Answer: C** 
20.	**Answer: B**  There are 5 different types of hydrogen for substitution.
21.	**Answer: B** A: Acidified potassium manganate would oxidise the alkene. The ester would be hydrolysed too. Ethanedioic acid is produced which can be further oxidised to form carbon dioxide. B: Carboxylic acid needs to be converted to a more reactive acyl chloride. C: X can undergo neutralisation with the carboxylic acid group under room conditions. When heated, the ester group would be hydrolysed. D: Na metal reacts with both the carboxylic acid and alcohol groups to produce 2 moles of hydrogen gas.
22.	**Answer: C** P contains either alcohol or carboxylic acid since it gives white fumes with PCl_5.

	A is incorrect as tertiary alcohols cannot be oxidised. B is incorrect as ketones cannot be oxidised. D is incorrect as side chain oxidation of benzene ring requires acidified potassium manganate(VII) instead.
23.	**Answer: B** Statement 2 is incorrect as $LiAlH_4$ would also reduce the ester group. Hydrogen with platinum catalyst can be used instead to only reduce the nitrile. Statement 3 is incorrect as W reacts with excess bromoethane to form $RN^+(CH_2CH_3)_3$ which is not basic. Statement 4 is correct. Y is ethanol and gives a positive iodoform test.
24.	**Answer: B** According to Markovnikov's rule, H would be added to the carbon atom in the C=C with more H. The structures of A and D are incorrect. Step 2: From molecular formula of E, bromine is substituted by –CN.
25.	**Answer: B** A is incorrect as the reaction does not involve the ester. C is incorrect as it has one missing $-CH_2$. D has the double bond at the wrong position.
26.	**Answer: B** Propagation: $CH_2Cl_2 + Cl\bullet \rightarrow \bullet CHCl_2 + \underline{HCl}$ $\bullet CHCl_2 + Cl_2 \rightarrow \underline{CHCl_3} + Cl\bullet$ $CHCl_3 + Cl\bullet \rightarrow \bullet CCl_3 + HCl$ $\bullet CCl_3 + Cl_2 \rightarrow \underline{CCl_4} + Cl\bullet$ Termination: $\bullet CCl_3 + \bullet CHCl_2 \rightarrow \underline{CCl_3CHCl_2}$
27.	**Answer: B (CLT for 2021 exam)**
28.	**Answer: A** **A:** 2-nitrophenol or 4-nitrophenol is formed which is a pale yellow precipitate. **B & C:** $-COCH_3$ is ring deactivating while $-CH_2CH_3$ and $-NH_2$ are ring activating. Hence, the electron density in phenylethanone is lower. It would undergo nitration at a slower rate and higher temperature. **D:** As –OH is ring activating, it does not require concentrated sulfuric acid to generate the electrophile.
29.	**Answer: D** During discharging, the cell behaves as a galvanic cell, hence reaction is spontaneous, ΔG is negative. At electrode X, Pb is oxidised to $PbSO_4$, hence X is anode, and $E^\ominus_2$ is more positive than $E^\ominus_1$.

	For 2 mol of electrons transferred during discharge, the overall equation is $Pb + PbO_2 + 2H^+ + 2HSO_4^- \rightarrow 2PbSO_4 + 2H_2O$. As the cell discharges, $[H^+]$ decreases, hence pH increases.
30.	**Answer: C** $2Cl^- \rightarrow Cl_2 + 2e^-$ $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ Same 10 cm^3 volume i.e. same mole of Cl_2 and O_2 are produced, hence amount of electron transfer in electrolysis 2 is double that of electrolysis 1. Q = It = nF, since time t and F are constant, doubling n would double current I.

PRELIMINARY EXAMINATIONS
HIGHER 2

TEMASEK
JUNIOR COLLEGE

CANDIDATE NAME										
CIVICS GROUP			/							
CENTER NUMBER	S		/			INDEX NUMBER				

CHEMISTRY **9729/02**

Paper 2 Structured Questions **24 August 2021**

2 hours

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

READ THESE INSTRUCTIONS FIRST

Write your Civics Group, centre number, 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 or graphs.
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 Examiner's Use	
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Total	

This document consists of **20** printed pages.

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

1 **(a)** Excited states can be studied to gain information about the energies of orbitals that are unoccupied in an atom's ground state. The excited state of an element, **Q**, is represented by the electronic configuration $1s^22s^22p^63s^23p^63d^44s^24p^1$.

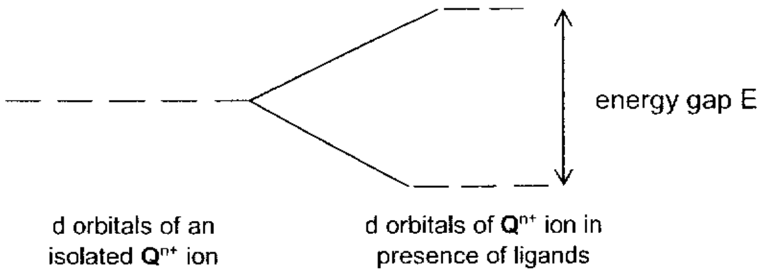
(i) Identify the element **Q**.

.... [1]

(ii) Draw the energy level diagram showing the electronic configuration of element **Q** in its ground state.

[2]

(iii) The arrangement of electrons in the d orbitals depends on the spin states of complexes. The following diagram shows how the d orbitals are split in an octahedral environment for the ion **Q**$^{n+}$.



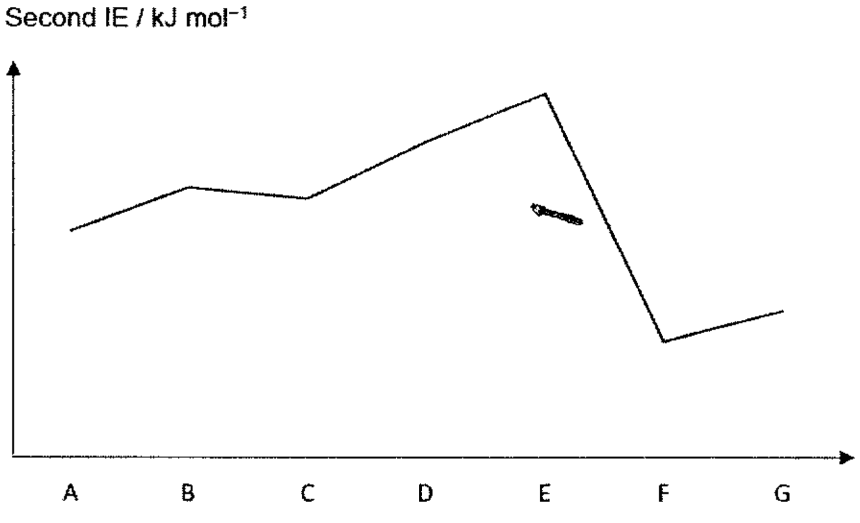
In a 'high spin' state, the electrons occupy all the d orbitals singly, before starting to pair up in the lower energy d orbitals.

In a 'low spin' state, the lower energy d orbitals are filled first, by pairing up if necessary, before the higher energy d orbitals are used.

Use diagrams like the one given to show the electronic configuration of a ground state **Q**$^{2+}$ ion in low spin state.

[1]

(b) The second ionisation energies of seven consecutive elements **A** to **G** in the Periodic Table are shown below.



(i) Write an equation for the second ionisation energy of oxygen.

.... [1]

[Turn over

(ii) Explain the discontinuity in second ionisation energies between **E** and **F**, and between **B** and **C**. Hence deduce which element **A** to **G** is oxygen.

....

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.... [3]

(c) **(i)** State and explain the variation in bonding in Period 3 oxides in terms of electronegativity.

....

....

....

....

.... [2]

W, **X**, **Y**, and **Z** are four consecutive elements in the fourth period of the Periodic Table. The letters are not the actual symbols of the elements.

W forms an oxide that reacts with both acids and bases.

Z is a solid that can exist as several different allotropes. **Z** burns in air to form ZO_2 which dissolves in water to form an acidic solution. This solution reacts with sodium hydroxide to form the salt Na_2ZO_3.

(ii) Suggest the identities of **W** and **Z**.

.... [1]

(iii) Write equations for the reactions of oxide of **W** with sodium hydroxide and hydrochloric acid respectively.

....

.... [2]

(iv) Write an equation for the formation of an acidic solution when ZO_2 dissolves in water.

.... [1]

[Total: 14]

[Turn over

2 **(a)** Chlorine reacts with iodine to form a compound **T**, ICl_7. When dissolved in an excess of aqueous potassium iodide, **T** liberates iodine, I_2, which is the only iodine-containing product in the reaction.

(i) State the oxidation number of iodine in ICl_7.

.... [1]

(ii) Write the equation for the reaction between **T** and potassium iodide.

.... [1]

(iii) Calculate the amount of iodine liberated when 1.00 g of **T** reacts with an excess of aqueous potassium iodide.

[1]

(iv) Sodium thiosulfate is a common reagent used for the reaction with iodine.

Write a balanced equation for the reaction between sodium thiosulfate and iodine and calculate the volume of 1.00 mol dm^{-3} sodium thiosulfate, in cm^3, required to react with all the iodine liberated in **(a)(iii)**.

[2]

(b) Chlorine is produced together with carbon monoxide when phosgene, $COCl_2$, undergoes dissociation according to the equation below:

$$COCl_2(g) \rightleftharpoons Cl_2(g) + CO(g)$$

The above reaction takes place in a 2 dm^3 reaction vessel. At the start of the reaction, there was 4.0 mol of phosgene in the vessel. When dynamic equilibrium was established, only 1.6 mol of phosgene was left.

(i) Write the K_c expression for the above reaction, stating its units.

....

.... [2]

(ii) Calculate the equilibrium amounts of CO and Cl_2, and hence, determine the value of K_c for the above reaction, showing your working clearly.

[2]

(iii) In the same reaction vessel, calculate the amount of phosgene to be removed from the equilibrium mixture in **(b)(ii)** in order to reduce the equilibrium amount of Cl_2 to 2.0 mol.

[2]

(iv) State *Le Chatelier's Principle*.

....

....

.... [1]

(v) State and explain how the equilibrium composition might change if the above reaction is subjected to a decrease in pressure.

....

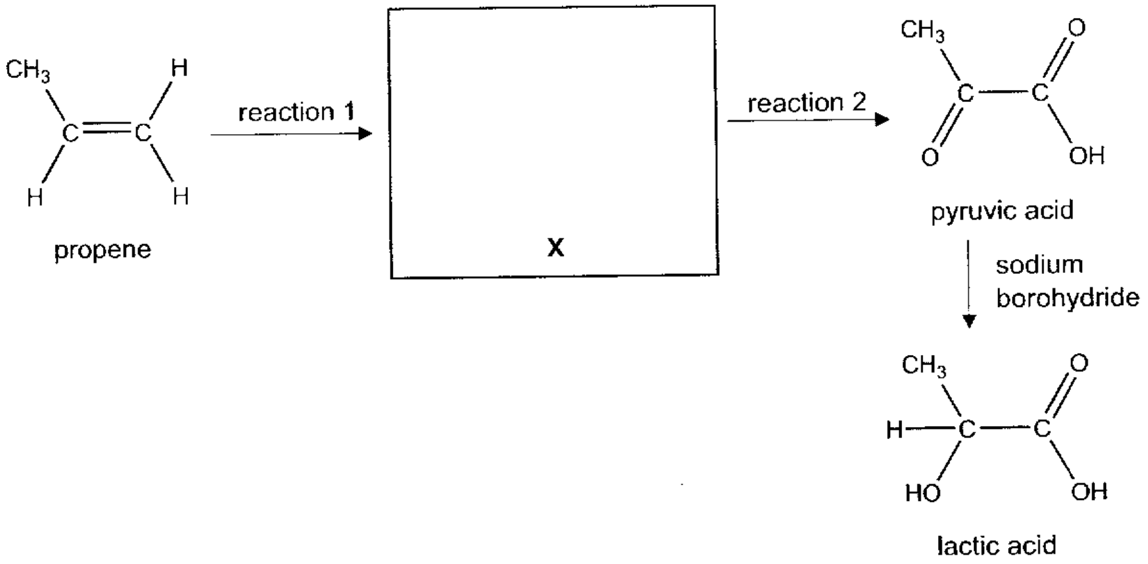
....

....

.... [2]

[Total: 14]

3 Propene and lactic acid are commonly used as feedstock for polymers.



(a) **(i)** Suggest reagents and conditions for reaction 1 and 2.

Reaction 1: ....

Reaction 2: ....

[2]

(ii) Suggest the structure of compound **X** in the box above. [1]

(b) Explain why sodium borohydride can reduce the carbonyl C=O bond in pyruvic acid but not C=C bond in propene.

....

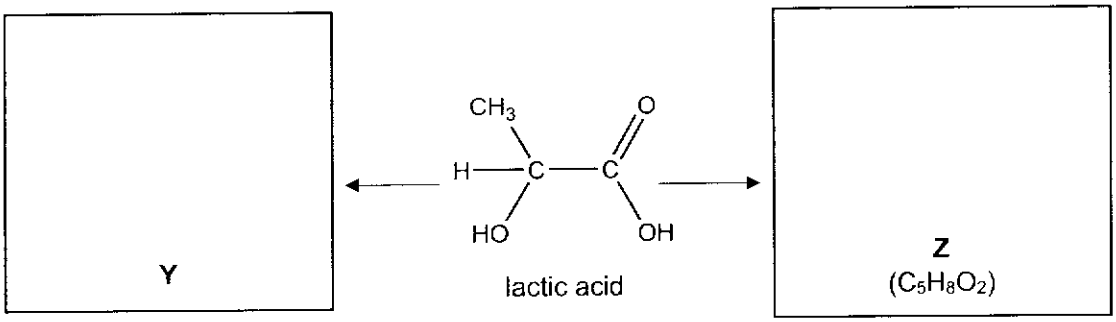
....

....

.... [2]

[Turn over

(c) The condensation of two molecules of lactic acid produces compound **Y** and **Z**.



(i) Compound **Y** is a cyclic ester derived from the condensation of two molecules of lactic acid.

Show the skeletal structure of compound **Y** in the box above. [1]

(ii) Explain why compound **Y** have low solubility in methanol.

....

....

.... [1]

(iii) The condensation of two lactic acid molecules also produces compound **Z** with the elimination of carbon dioxide and water.

Compound **Z** reacts with 2 moles of 2,4-dinitrophenylhydrazaine. It forms 1 mole of CHI_3 upon reaction with aqueous alkaline iodine and does not give silver mirror with Tollen's reagent.

Suggest the structure of compound **Z** in the box above. [1]

(iv) Explain why compound **Z** has a lower boiling point than lactic acid.

....

....

....

.... [2]

[Total: 10]

4 **(a)** Nitrogen monoxide, NO(g), is a colourless, toxic gas that is formed by the oxidation of nitrogen. It can be reduced by hydrogen, H_2(g), under certain conditions to form harmless products.

$$2NO(g) + 2H_2(g) \longrightarrow N_2(g) + 2H_2O(l)$$

(i) Define the term 'rate of reaction'.

....

....

.... [1]

(ii) Identify a change in the reaction mixture that would allow the rate of reaction to be measured.

....

.... [1]

A series of experiments was conducted to determine the rate equation for the above reaction. The following data was obtained.

Experiment	Initial [NO] / mol dm^{-3}	Initial [H_2] / mol dm^{-3}	Initial Rate / mol dm^{-3} s^{-1}
1	2.50 x 10^{-3}	2.50 x 10^{-3}	1.27 x 10^{-3}
2	2.50 x 10^{-3}	4.60 x 10^{-3}	2.34 x 10^{-3}
3	5.00 x 10^{-4}	7.50 x 10^{-3}	1.52 x 10^{-4}

(iii) Determine the order of reaction with respect to NO and H_2. Hence state the rate equation.

[3]

[Turn over

(iv) Using the data from Experiment 2, calculate the rate constant, k.

[1]

The reaction was believed to proceed in three steps.

Step 1 : $2NO \rightarrow N_2O_2$

Step 2 : $N_2O_2 + H_2 \rightarrow N_2O + H_2O$

Step 3 : $N_2O + H_2 \rightarrow N_2 + H_2O$

(v) Deduce which of the 3 steps is the rate-determining step.

....

....

....

.... [1]

(b) Another experiment was conducted using 2.00 mol dm^{-3} of NO and 0.020 mol dm^{-3} H_2. The experiment was found to have a half-life of 2 s.

(i) Use the axes below to construct a graph of the variation in the concentration of 0.020 mol dm^{-3} $H_2(g)$ under the conditions specified.

[1]

(ii) Determine the half-life if the experiment was repeated using

(I) 0.040 mol dm^{-3} H_2 and same concentration of NO

(II) 0.020 mol dm^{-3} H_2 and concentration of NO doubled.

Show clearly how you arrive at your answer.

[2]

(iii) NO can be easily oxidised to NO_2 which can act as a catalyst in the oxidation of atmospheric sulfur dioxide.

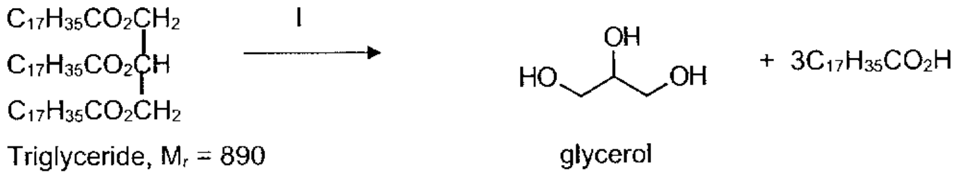
Write equations to show how NO_2 acts as a catalyst in this process.

....

....

.... [2]

(c) Recently much interest has been shown in the production of the fuel biodiesel from algae. 50% of the mass of the dried algae are triglycerides. To convert triglycerides into biodiesel, the following processes are carried out.



$$C_{17}H_{35}CO_2H \xrightarrow{\text{II}} C_{17}H_{35}CO_2CH_3$$

Biodiesel, M_r = 298

(i) State the reactants and conditions for reactions I and II.

Reaction I : ....

Reaction II : ....

[2]

(ii) Calculate the mass of biodiesel that can be produced from 1000 kg of dried algae.

[2]

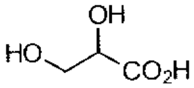
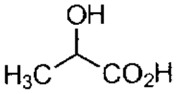
(iii) The production of biodiesel is at present an expensive process. Suggest a reason why the development of biodiesel as an alternative to fossil fuels is important.

....

....

.... [1]

Glycerol, a by-product of biodiesel production, can be selectively oxidised to glyceric acid and lactic acid which have widespread applications. The table below shows the pK_a values of the acids.

Acid	pK_a
 Glyceric acid	3.42
 Lactic Acid	3.86

(iv) Explain the difference in the relative acidity of the two acids.

....

....

....

....

.... [2]

(v) 20 cm^3 of 0.20 mol dm^{-3} glyceric acid is added to 40 cm^3 of 0.10 mol dm^{-3} sodium hydroxide solution. Calculate the pH of the resultant solution.

[3]

[Total: 22]

5 **(a)** Hydrazine, N_2H_4, was first used as a component in rocket fuel in World War 2.

(i) Using the VSEPR theory, state and explain

- the shape of hydrazine around each N atom;
- the H-N-H bond angle.

....

....

....

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....

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.... [3]

(ii) Hence, draw the structure of hydrazine, showing clearly the shape around one nitrogen atom.

[1]

When combined with hydrogen peroxide, the reaction produced nitrogen gas and water vapour, and released a large amount of energy that propelled the rocket to space.

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O \qquad \Delta H_r$$

(iii) What do you understand by the term *bond energy* of a covalent bond.

....

....

....

.... [2]

(iv) Calculate the enthalpy change, ΔH_r, of the gaseous reaction between hydrazine and hydrogen peroxide.

[2]

(b) When two pure liquids, A and B, which do not react, are mixed together, heat may be absorbed or released depending on the relative strength of intermolecular forces of attraction formed in the mixture.

$$A(l) + B(l) \rightarrow A\text{---}B\ (l) \qquad \Delta H_{mix}$$

--- refers to the intermolecular forces of attraction between liquids A and B.

Enthalpy change of mixing, ΔH_{mix}, is the enthalpy change when 1 mole each of pure A and pure B are added to form a binary A---B solution.

The enthalpy change of mixing of ethyl ethanoate and trichloromethane is determined experimentally in an insulated calorimeter and the following data is collected.

	ethyl ethanoate	trichloromethane
Molar mass / g mol^{-1}	88.0	119.5
Mass / g	8.80	–
Specific heat capacity / J g^{-1} K^{-1}	1.92	0.96
Initial temperature / °C	31.2	31.2
Final temperature / °C	40.7	40.7

(i) Calculate the heat change of ethyl ethanoate during the mixing process.

[1]

(ii) The heat change for an equimolar of trichloromethane at the same initial temperature is 109 J.

Calculate the heat change of the mixture and hence the enthalpy change of mixing, ΔH_{mix}, of ethyl ethanoate and trichloromethane.

[2]

(iii) A student claimed that the heat change was due to the formation of intermolecular forces of attraction between ethyl ethanoate and trichloromethane molecules.

Comment on the student's claim and explain your answer.

....

....

....

.... [1]

(iv) With reference to structure and bonding, explain the significance of the sign of ΔH_{mix} in **(b)(ii)** and hence, predict the observation of mixing ethyl ethanoate and trichloromethane.

....

....

....

....

....

....

....

.... [3]

[Total: 15]

PRELIMINARY EXAMINATIONS
HIGHER 2

TEMASEK
JUNIOR COLLEGE

CANDIDATE NAME

CIVICS GROUP			/		
CENTER NUMBER	S		/		

INDEX NUMBER				

CHEMISTRY **9729/02**

Paper 2 Structured Questions **24 August 2021**

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

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Write in dark blue or black pen.
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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.

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Total	

This document consists of **XX** printed pages and **XX** blank page.

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

1 **(a)** Excited states can be studied to gain information about the energies of orbitals that are unoccupied in an atom's ground state. The excited state of an element, **Q**, is represented by the electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4 4s^2 4p^1$.

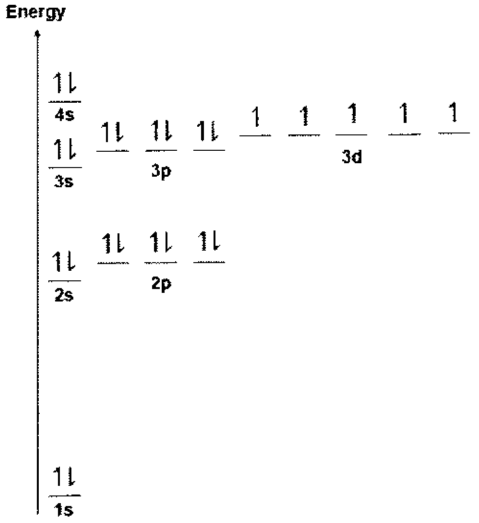
(i) Identify the element **Q**. [1]

Since the total number of electrons is 25, • Q is manganese.

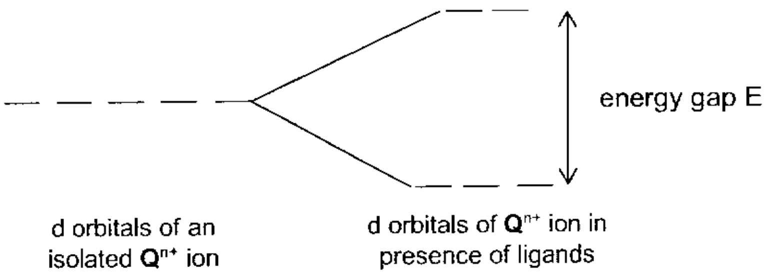
(ii) Draw the energy level diagram showing the electronic configuration of element **Q** in its ground state. [2]

- **Electronic configuration of Q in ground state - $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$**

  (Either written out or shown correctly in energy level diagram)
- **Energy level diagram with axis and orbitals labelled, energy levels converge as distance from nucleus increase, energy diff between subshells < between shells.**



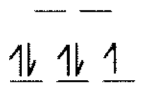
CLT **(iii)** The arrangement of electrons in the d orbitals depends on the spin states of complexes. The following diagram shows how the d orbitals are split in an octahedral environment for the ion Q^{n+}.



In a 'high spin' state, the electrons occupy all the d orbitals singly, before starting to pair up in the lower energy d orbitals.

In a 'low spin' state, the lower energy d orbitals are filled first, by pairing up if necessary, before the higher energy d orbitals are used.

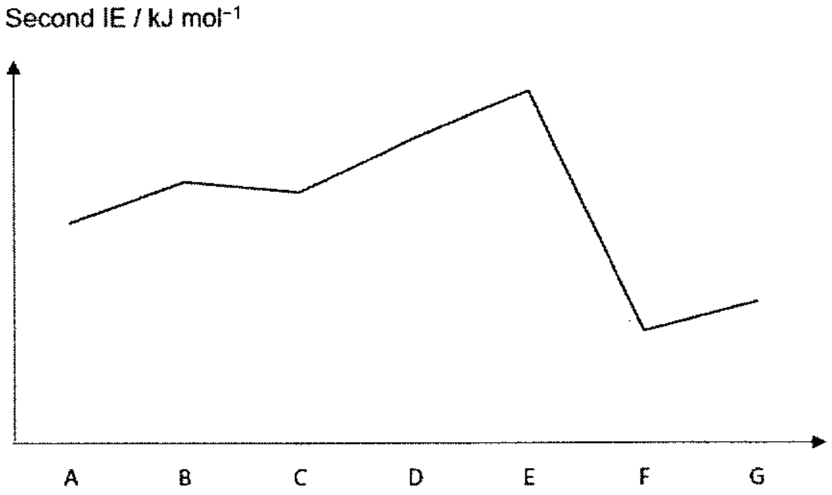
Use diagrams like the one given to show the electronic configuration of a ground state **Q**$^{2+}$ ion in low spin state. [1]



Q^{2+}: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$

- **1 mark for correct diagram**

(b) The second ionisation energies of seven consecutive elements **A** to **G** in the Periodic Table are shown below.



(i) Write an equation for the second ionisation energy of oxygen. [1]

- **$O^+ (g) \rightarrow O^{2+} (g) + e^-$**

Note: State symbols must be included for IE equation.

(ii) Explain the discontinuity in second ionisation energies between **E** and **F**, and between **B** and **C**. Hence deduce which element **A** to **G** is oxygen. [3]

- **There is a big drop in second IE from element E to F. Second electron in element F is removed from outer electronic shell. Element F is a Group 2 element (as it has two valence electrons).**

OR

There is a big drop in second IE from element E to F. Second electron in element E is removed from inner electronic shell. Element E is a Group 1 element (as it has one valence electron).

- **Hence element B is oxygen (Group 16).**
- **Second IE of C (Group 17) involves the removal of paired 2p electron which experiences inter-electronic repulsion. Hence, less energy is required to remove the paired electron from C^+ ion.**

(c) (i) State and explain the variation in bonding in Period 3 oxides in terms of electronegativity. [2]

- **Across the Period, electronegativity of elements increases, electronegativity differences between the elements and oxygen decreases resulted in sharing of electrons.**
- **The oxides become changes from ionic to covalent/increasingly covalent in character across Period 3.**

W, **X**, **Y**, and **Z** are four consecutive elements in the fourth period of the Periodic Table. The letters are not the actual symbols of the elements.

W forms an oxide that reacts with both acids and bases.

Z is a solid that can exist as several different allotropes. **Z** burns in air to form ZO_2 which dissolves in water to form an acidic solution. This solution reacts with sodium hydroxide to form the salt Na_2ZO_3.

(ii) Suggest the identities of **W** and **Z**. [1]

- **W is gallium, Z is selenium.**

(iii) Write equations for the reactions of oxide of **W** with sodium hydroxide and hydrochloric acid respectively. [2]

- $W_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaW(OH)_4$
- $W_2O_3 + 6HCl \rightarrow 2WCl_3 + 3H_2O$

(iv) Write an equation for the formation of an acidic solution when ZO_2 dissolves in water. [1]

- $ZO_2 + H_2O \rightarrow H_2ZO_3$

[Total: 14]

[Turn over

2 **(a)** Chlorine reacts with iodine to form a compound **T**, ICl_7. When dissolved in an excess of aqueous potassium iodide, **T** liberates iodine, I_2, which is the only iodine-containing product in the reaction.

(i) State the oxidation number of iodine in ICl_7. [1]

• +7

(ii) Write the equation for the reaction between **T** and potassium iodide. [1]

• $\mathbf{ICl_7 + 7KI \rightarrow 4I_2 + 7KCl}$

+7 7(-1) 0

(iii) Calculate the amount of iodine liberated when 1.00 g of **T** reacts with an excess of aqueous potassium iodide. [1]

Amount of $\mathbf{ICl_7}$

= 1/(126.9 + 7 x 35.5)

= $\mathbf{2.66 \times 10^{-3}}$ **mol**

Amount of iodine

= $\mathbf{4 \times 2.66 \times 10^{-3}}$

• = $\mathbf{1.07 \times 10^{-2}}$ **mol** (allow ecf from (a)(ii))

(iv) Sodium thiosulfate is a common reagent used for the reaction with iodine.

Write a balanced equation for the reaction between sodium thiosulfate and iodine and calculate the volume of 1.00 mol dm^{-3} sodium thiosulfate, in cm^3, required to react with all the iodine liberated in **(a)(iii)**. [2]

• $\mathbf{I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}}$

Volume of sodium thiosulfate required

= $\mathbf{(1.07 \times 10^{-2} \times 2)/1 \times 1000}$

= • 21.3 $\mathbf{cm^3}$ (allow ecf from a(iii))

(b) Chlorine is produced together with carbon monoxide when phosgene, $COCl_2$, undergoes dissociation according to the equation below:

$$COCl_2(g) \rightleftharpoons Cl_2(g) + CO(g)$$

The above reaction takes place in a 2 dm^3 reaction vessel. At the start of the reaction, there was 4.0 mol of phosgene in the vessel. When dynamic equilibrium was established, only 1.6 mol of phosgene was left.

(i) Write the K_c expression for the above reaction, stating its units. [2]

- $$K_c = \frac{[Cl_2][CO]}{[COCl_2]}$$

- **Units: mol dm^{-3}**

(ii) Calculate the equilibrium amounts of CO and Cl_2, and hence, determine the value of K_c for the above reaction, showing your working clearly. [2]

	$COCl_2(g)$	**⇌**	**$Cl_2(g)$**	**+**	**$CO(g)$**
Initial amount / mol	**4.0**		**0**		**0**
Change / mol	**- 2.4**		**+ 2.4**		**+ 2.4**
Eqm amount / mol	**1.6**		**2.4**		**2.4**

- **Equilibrium amounts of CO and Cl_2 = <u>2.4 mol</u> respectively**

- $$K_c = \frac{(\frac{2.4}{2})(\frac{2.4}{2})}{(\frac{1.6}{2})} = \underline{1.80}$$ **mol dm^{-3} (ignore units in marking)**

(iii) In the same reaction vessel, calculate the amount of phosgene to be removed from the equilibrium mixture in **(b)(ii)** in order to reduce the equilibrium amount of Cl_2 to 2.0 mol. [2]

Let x be the amount of phosgene that needs to be removed.

	$COCl_2(g)$	**⇌**	**$Cl_2(g)$**	**+**	**$CO(g)$**
Initial amount / mol	**1.6 - x**		**2.4**		**2.4**
Change / mol	**+ 0.4**		**- 0.4**		**- 0.4**
Eqm amount / mol	**2.0 - x**		**2.0**		**2.0**

$$K_c = \frac{(\frac{2.0}{2})(\frac{2.0}{2})}{(\frac{2.0-x}{2})} = 1.8$$

- **Working**
- **x = 0.889 mol**

(iv) State *Le Chatelier's Principle*. [1]

- ***Le Chatelier's Principle*** **states that when a system at dynamic equilibrium is subjected to a change which disturbs the equilibrium, the system will react in a way so as to counteract the effect of the change to re-establish equilibrium.**

(v) State and explain how the equilibrium composition might change if the above reaction is subjected to a decrease in pressure. [2]

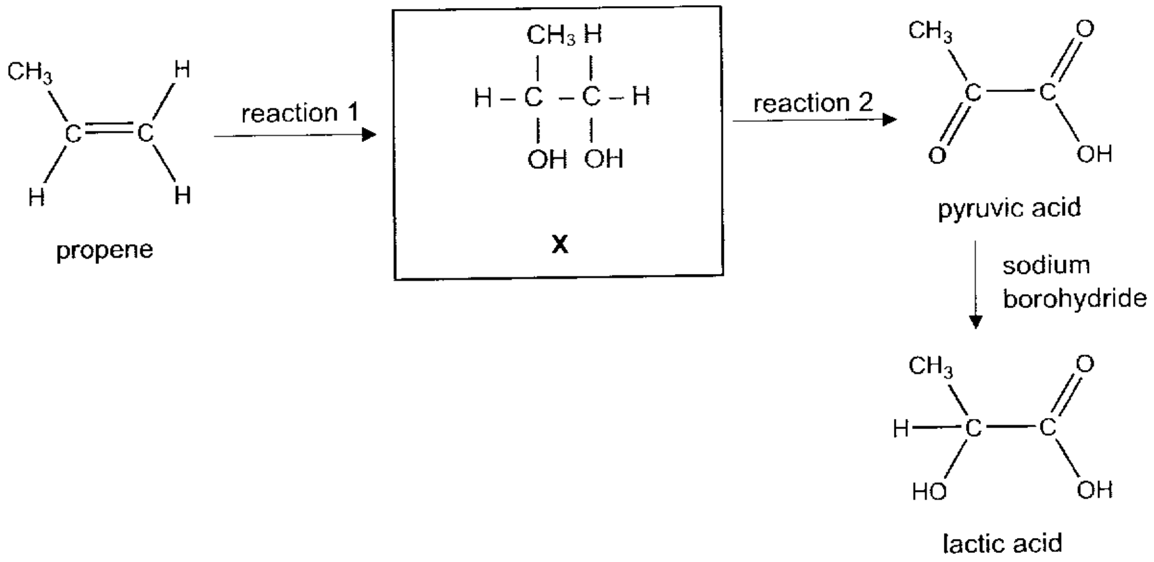
By *Le Chatelier's Principle*, a decrease in pressure will cause the

- **equilibrium position to shift right to increase the number of moles of gases to increase pressure.**

- **The new equilibrium mixture contains more products, Cl_2 and CO, and less reactant, $COCl_2$.**

[Total: 14]

3 Propene and lactic acid are commonly used as feedstock for polymers.



(a) **(i)** Suggest reagents and conditions for reaction 1 and 2. [2]

- **cold acidic dilute $KMnO_4$ or cold alkaline dilute $KMnO_4$**

[Note: Do not accept hot or concentrated]

- **$K_2Cr_2O_7/H^+$, heat or $KMnO_4/H^+$, heat**

(ii) Suggest the structure of compound **X** in the box above. [1]

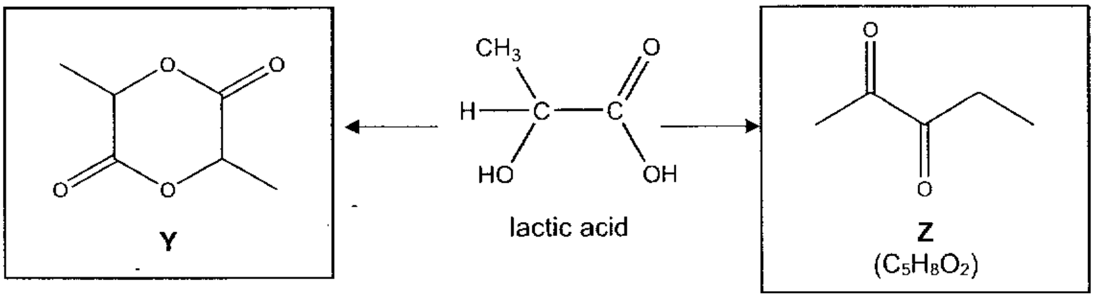
(b) Explain why sodium borohydride can reduce the carbonyl C=O bond in pyruvic acid but not C=C bond in propene. [2]

C in C=O is ✓electron deficient due to presence of electronegative O hence it is susceptible to nucleophilic attack by ✓ nucleophiles like BH_4^-.

C=C is ✓electron rich hence does not react with nucleophiles like BH_4^-.

3✓ = 2 marks ; 2✓ = 1 mark

(c) The condensation of two molecules of lactic acid produces compound **Y** and **Z**.



Y

lactic acid

Z
($C_5H_8O_2$)

(i) Compound **Y** is a cyclic ester derived from the condensation of two molecules of lactic acid.

Show the skeletal structure of compound **Y** in the box above. [1]

(ii) Explain why compound **Y** have low solubility in methanol. [1]

• The energy released from the interactions (pd-pd / H-bonds) formed with methanol are insufficient to overcome the hydrogen bonds between methanol molecules hence it is less soluble in methanol.

(iii) The condensation of two lactic acid molecules also produces compound **Z** with the elimination of carbon dioxide and water.

Compound **Z** reacts with 2 moles of 2,4-dinitrophenylhydrazaine. It forms 1 mole of CHI_3 upon reaction with aqueous alkaline iodine and does not give silver mirror with Tollen's reagent.

Suggest the structure of compound **Z** in the box above. [1]

(iv) Explain why compound **Z** has a lower boiling point than lactic acid. [2]

✓ Both have simple molecular structure.

✓ More energy is required to break the ✓ hydrogen bonds between lactic acid molecules, compared to the ✓ the permanent dipole – permanent dipole interaction between molecules of compound Z. Hence, lactic has a higher boiling point than compound Z.

2✓ 1mark

[Total: 10]

4 (a) Nitrogen monoxide, NO(g), is a colourless, toxic gas that is formed by the oxidation of nitrogen. It can be reduced by hydrogen, H_2(g), under certain conditions to form harmless products.

$$2NO(g) + 2H_2(g) \longrightarrow N_2(g) + 2H_2O(l)$$

(i) Define the term 'rate of reaction'. [1]

Decrease (or change) in reactant concentration per unit time or increase (or change) in product concentration per unit time.

(ii) Identify a change in the reaction mixture that would allow the rate of reaction to be measured. [1]

Decrease (change) in gas volume or pressure.

A series of experiments was conducted to determine the rate equation for the above reaction. The following data was obtained.

Experiment	Initial [NO] / mol dm^{-3}	Initial [H_2] / mol dm^{-3}	Initial Rate / mol dm^{-3} s^{-1}
1	2.50×10^{-3}	2.50×10^{-3}	1.27×10^{-3}
2	2.50×10^{-3}	4.60×10^{-3}	2.34×10^{-3}
3	5.00×10^{-4}	7.50×10^{-3}	1.52×10^{-4}

(iii) Determine the order of reaction with respect to NO and H_2. Hence state the rate equation. [3]

Using Expt 1 & 2

[NO] kept constant, [H_2] increases by $4.60 \times 10^{-3}/2.50 \times 10^{-3} = 1.84$ times, rate increases by $2.34 \times 10^{-3}/1.27 \times 10^{-3} = 1.84$ times.

- **First order wrt [H_2]**

Using Expt 1 & 3

Rate = k$[NO]^y[H_2]$

$1.27 \times 10^{-3}/1.52 \times 10^{-4} = k(2.50 \times 10^{-3})^y(2.50 \times 10^{-3}) / k(5.00 \times 10^{-4})^y(7.50 \times 10^{-3})$

- **y = 2, Second order wrt [NO]**
- **Rate = k$[NO]^2[H_2]$**

(iv) Using the data from Experiment 2, calculate the rate constant, k. [1]

Rate = k$[NO]^2[H_2]$

$2.34 \times 10^{-3} = k(2.50 \times 10^{-3})^2(4.60 \times 10^{-3})$

k = 8.14×10^4 mol^{-2} dm^6 s^{-1}

The reaction was believed to proceed in three steps.

Step 1 : $2NO \rightarrow N_2O_2$
Step 2 : $N_2O_2 + H_2 \rightarrow N_2O + H_2O$
Step 3 : $N_2O + H_2 \rightarrow N_2 + H_2O$

(v) Deduce which of the 3 steps is the rate-determining step. [1]

From the rate equation, the rate-determining step (slow step) must have two NO molecules reacting with one H_2 molecule.

Step 2 is the rate-determining step as N_2O_2 is the intermediate from two NO molecules. Combining steps 1 and 2 gives two NO and one H_2 which is consistent with the rate equation.

Alternative

Step 2 is rate-determining step,

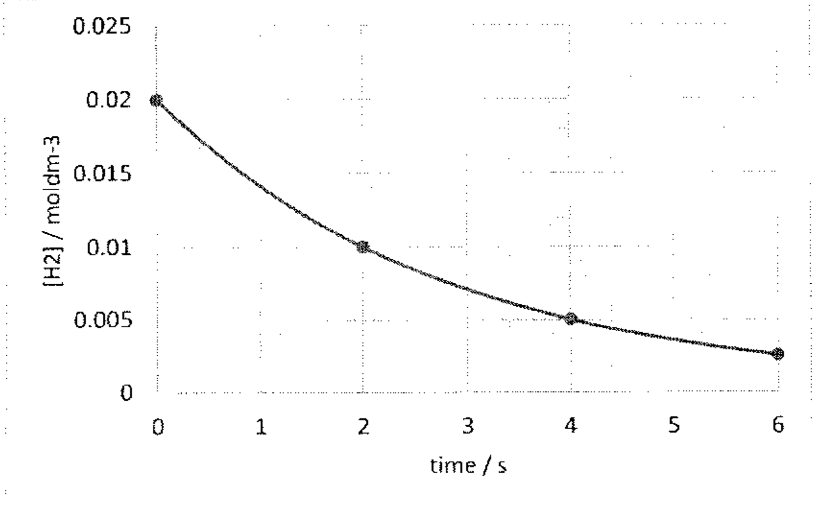
rate = $k[N_2O_2][H_2]$

Since 2NO forms $1N_2O_2$,

rate = $k[NO]^2[H_2]$

(b) Another experiment was conducted using 2.00 mol dm^{-3} of NO and 0.020 mol dm^{-3} H_2. The experiment was found to have a half-life of 2 s.

(i) Use the axes below to construct a graph of the variation in the concentration of 0.020 mol dm^{-3} $H_2(g)$ under the conditions specified. [1]



(ii) Determine the half-life if the experiment was repeated using

(I) 0.040 mol dm^{-3} H_2 and same concentration of NO

(II) 0.020 mol dm^{-3} H_2 and concentration of NO doubled.

Show clearly how you arrive at your answer. [2]

Rate = k$[NO]^2[H_2]$

Using large excess of NO, reaction becomes pseudo first order.

Rate = k'$[H_2]$ where k' = k$[NO]^2$

$t_{½}$ = ln 2/k'

(I) • $t_{½}$ = 2 s since $t_{½}$ is a constant for pseudo first order reaction and is independent of the $[H_2]$

(II) • $t_{½}$ = ln 2 / k'

= ln 2 / (k x $[NO]^2$)

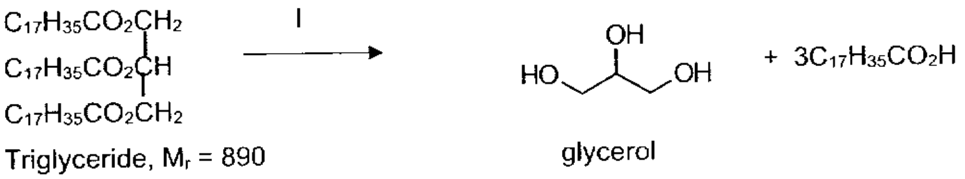
= 2/4 = 0.5 s

(iii) NO can be easily oxidised to NO_2 which can act as a catalyst in the oxidation of atmospheric sulfur dioxide.

Write equations to show how NO_2 acts as a catalyst in this process. [2]

- **$SO_2(g) + NO_2(g) \rightarrow SO_3(g) + NO(g)$**
- **$NO(g) + ½\,O_2(g) \rightarrow NO_2(g)$**

(c) Recently much interest has been shown in the production of the fuel biodiesel from algae. 50% of the mass of the dried algae are triglycerides. To convert triglycerides into biodiesel, the following processes are carried out.



$$C_{17}H_{35}CO_2H \xrightarrow{\text{II}} C_{17}H_{35}CO_2CH_3$$

Biodiesel, M_r = 298

(i) State the reactants and conditions for reactions I and II. [2]

I : • **dilute HC*l*, heat**

II : • **CH_3OH, conc.H_2SO_4, heat**

(ii) Calculate the mass of biodiesel that can be produced from 1000kg of dried algae.[2]

1000 kg algae contains 500 kg triglycerides

- **890 g of triglyceride produces 3 × 298 = 894 g of biodiesel**
- **500 kg produces 500 × 894/890 = 502 kg biodiesel**

Alternative

1000 kg algae contains 500 kg triglycerides

Amt of triglyceride = (500 x 1000)/890

= 562 mol

- **No. of moles of of $C_{17}H_{35}CO_2H$ produced = 562 x 3**

  = 1686 mol

  = amt of biodiesel

Mass of biodiesel = 1686 x 298

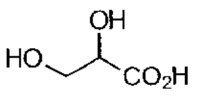
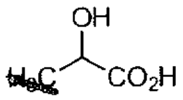
= 502 kg

(iii) The production of biodiesel is at present an expensive process. Suggest a reason why the development of biodiesel as an alternative to fossil fuels is important. [1]

Fossil fuels : causes serious environmental problems (global warming), imminent depletion

Biodiesel : renewable/sustainable, smaller C footprint (less global warming)

Glycerol, a by-product of biodiesel production, can be selectively oxidised to glyceric acid and lactic acid which have widespread applications. The table below shows the pK_a values of the acids.

Acid	pK_a
 Glyceric acid	3.42
 Lactic Acid	3.86

(iv) Explain the difference in the relative acidity of the two acids. [2]

•• **Glyceric acid is the √ stronger acid as it has √ 2 electron-withdrawing –OH groups compared to lactic acid with only 1 –OH group. The greater the number of –OH groups, the √ better the dispersal of the negative charge and hence the more √ stable carboxylate ion.**

(Lactic acid also has an electron donating methyl group that increases the charge density of the lactate ion resulting in a less stable lactate ion.)

2 √ : 1m

(v) 20 cm^3 of 0.20 mol dm^{-3} glyceric acid is added to 40 cm^3 of 0.10 mol dm^{-3} sodium hydroxide solution. Calculate the pH of the resultant solution. [3]

Amount of salt = 20/1000 x 0.20 mol

= 4.00 x 10^{-3} mol

- **[Salt] = 1000/60 x 4.0 x 10^{-3} mol dm^{-3}**

= 6.67 x 10^{-2} mol dm^{-3}

pK_a of acid = 3.42

pK_b of glycerate = 14 – 3.42

= 10.6

K_b = 2.51 x 10^{-11} mol dm^{-3}

- **[OH$^-$] = √(K_b x c**

= √(2.51 x 10^{-11} x 6.67 x 10^{-2})

= 1.29 x 10^{-6} mol dm^{-3}

pOH = -lg[OH$^-$]

= -lg(1.29 x 10^{-6})

= 5.89

- **pH = 14 - 5.89**

= 8.11

[Total: 22]

5 (a) Hydrazine, N_2H_4, was first used as a component in rocket fuel in World War 2.

(i) Using the VSEPR theory, state and explain

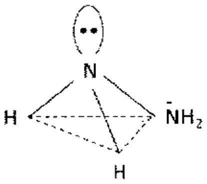
- the shape of hydrazine around each N atom;
- the H-N-H bond angle. [3]

There are ✓ 3 bond pairs and 1 lone pair of electrons in the outer/valence shell of each central N. By VSEPR theory, ✓ to maximise stability and minimise repulsion, the ✓ electron geometry is tetrahedral. Hence the shape is ✓ trigonal pyramidal.

Since ✓ lone pair – bond pair repulsion is greater than bond pair – bond pair repulsion, the H-N-H bond angle will be ✓ 107°.

Every 2 ✓ = 1 mark

(ii) Hence, draw the structure of hydrazine, showing clearly the shape around one nitrogen atom. [1]



When combined with hydrogen peroxide, the reaction produced nitrogen gas and water vapour, and released a large amount of energy that propelled the rocket to space.

$$N_2H_4 + 2H_2O_2 \rightarrow N_2 + 4H_2O \qquad \Delta H_r$$

(iii) What do you understand by the term *bond energy* of a covalent bond. [2]

Bond energy is the • average energy required to break one mole of covalent bond in the gas phase into constituent gaseous atoms under standard conditions of 298 K and 1 bar.

The • larger the bond energy, the stronger the covalent bond.

(iv) Calculate the enthalpy change, ΔH_r, of the gaseous reaction between hydrazine and hydrogen peroxide. [2]

Bonds broken: 1 N-N, 4 N-H, 2 O-O, 4 O-H

Bonds formed: 1 N≡N, 8 O-H

Energy absorbed during bond breaking

= 160 + 4(390) + 2(150) + 4(460) = 3860 kJ

Energy released during bond forming = 944 + 8(460) = 4624 kJ

• correct energy released and absorbed

ΔH_r = 3860 + (-4624) = • -764 kJ mol^{-1}

(b) When two pure liquids, A and B, which do not react, are mixed together, heat may be absorbed or released depending on the relative strength of intermolecular forces of attraction formed in the mixture.

$$A(l) + B(l) \rightarrow A\text{---}B\ (l) \qquad \Delta H_{mix}$$

--- refers to the intermolecular forces of attraction between liquids A and B.

Enthalpy change of mixing, ΔH_{mix}, is the enthalpy change when 1 mole each of pure A and pure B are added to form a binary A---B solution.

The enthalpy change of mixing of ethyl ethanoate and trichloromethane is determined experimentally in an insulated calorimeter and the following data is collected.

	ethyl ethanoate	trichloromethane
Molar mass / g mol^{-1}	88.0	119.5
Mass / g	8.80	–
Specific heat capacity / J g^{-1} K^{-1}	1.92	0.96
Initial temperature / °C	31.2	31.2
Final temperature / °C	40.7	40.7

(i) Calculate the heat change of ethyl ethanoate during the mixing process. [1]

Heat evolved = mcΔT = 8.8(1.92)(40.7 – 31.2) = • 161 J

(ii) The heat change for an equimolar of trichloromethane at the same initial temperature is 109 J.

Calculate the heat change of the mixture and hence the enthalpy change of mixing, ΔH_{mix}, of ethyl ethanoate and trichloromethane. [2]

Total heat evolved = 161 + 109 = • 270 J

ΔH_{mix} = -270/(8.8/88) = • -2.70 kJ mol^{-1}

(iii) A student claimed that the heat change was due to the formation of intermolecular forces of attraction between ethyl ethanoate and trichloromethane molecules.

Comment on the student's claim and explain your answer. [1]

Student is • incorrect as heat energy absorbed to break the intermolecular forces of attraction between ethyl ethanoate molecules and between trichloromethane molecules needs to be considered as well.

(iv) With reference to structure and bonding, explain the significance of the sign of ΔH_{mix} in **(b)(ii)** and hence, predict the observation of mixing ethyl ethanoate and trichloromethane. [3]

Both ethyl ethanoate and trichloromethane have ✓ simple molecular structure. ✓ Formation of permanent dipole - permanent dipole between ethyl ethanoate and trichloromethane molecules ✓ release sufficient energy to break the ✓ permanent dipole - permanent dipole between individual molecules. There is a net release of energy, so $\Delta H_{mix} < 0$.

Hence, ethyl ethanoate and trichloromethane are • miscible and form a homogeneous solution.

Every 2 ✓ = 1 mark

[Total: 15]