Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

A410U10-1

Z22-A410U10-1

MONDAY, 13 JUNE 2022 – MORNING

CHEMISTRY – A level component 1

Physical and Inorganic Chemistry

2 hours 30 minutes

For Examiner's use only			
	Question	Maximum Mark	Mark Awarded
Section A	1. to 8.	15	
Section B	9.	25	
	10.	21	
	11.	15	
	12.	17	
	13.	27	
	Total	120	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will need a:
- calculator;
- **Data Booklet** supplied by WJEC.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.
Do not use gel pen or correction fluid.
You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

Candidates are advised to allocate their time appropriately between **Section A (15 marks)** and **Section B (105 marks)**.

INFORMATION FOR CANDIDATES

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

The maximum mark for this paper is 120.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q.9**(c)(i) and **Q.13**(a).

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SECTION A

Answer **all** questions.

1. Write the electron configuration of a silicon atom. [1]

.....

2. The electronegativity values of some elements are listed in the table.

Element	Al	C	Cl	H	O
Electronegativity value	1.5	2.5	3.0	2.1	3.5

(a) Label the bonds below with $\delta+$ and $\delta-$ to show any dipoles that are present. [1]

C — Cl H — Cl O — Cl

(b) Give a reason why aluminium chloride is covalent. [1]

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3. Draw a dot-and-cross diagram to show the bonding in the molecule BeF_2. [1]

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4. Explain why the first ionisation energy of nitrogen is higher than that of oxygen. [2]

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5. Sodium hydroxide is a strong base.

(a) Calculate the pH of a 0.200 mol dm^{-3} solution of NaOH at 298 K. [2]

pH = ...

(b) Suggest, giving a reason, the pH of a solution of sodium ethanoate. [1]

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.....

.....

6. The first ionisation energy of magnesium is 738 kJ mol^{-1}. Calculate the frequency of light that would correspond to this energy. [2]

Frequency = ... Hz

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7. Give the most stable oxidation state of lead, giving a reason why this is more stable than its other common oxidation state. [1]

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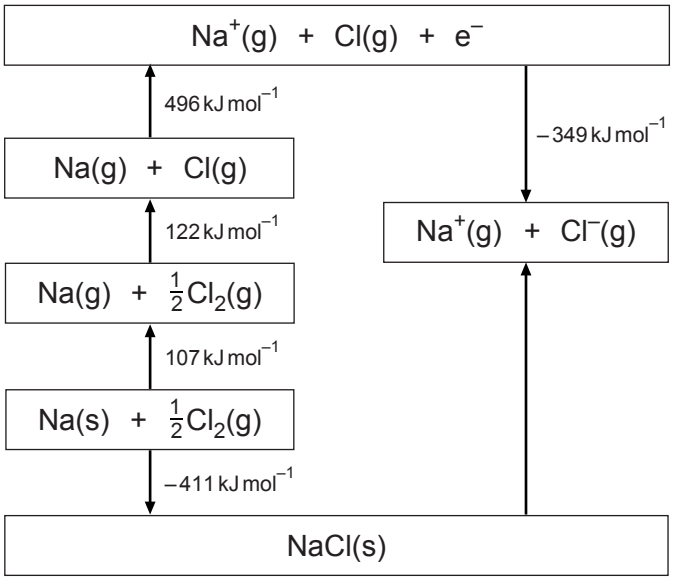
8. The Born-Haber cycle shown represents the enthalpy changes during the formation of sodium chloride.



(a) State the name of the enthalpy change that has a value of $-349\,kJ\,mol^{-1}$. [1]

.....

(b) Calculate the enthalpy change of lattice breaking of sodium chloride. [2]

Enthalpy change of lattice breaking = ... kJ mol^{-1}

15

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SECTION B

Answer **all** questions.

9. Cerium is a metallic element in the f-block of the Periodic Table.

(a) Cerium has four natural isotopes. The relative isotopic masses and percentage abundances of these isotopes are given in the table.

Isotope	Relative isotopic mass	Percentage abundance
^{136}Ce	135.9	0.19
^{138}Ce	137.9	0.25
^{140}Ce	139.9	88.45
^{142}Ce	141.9	11.11

(i) State what is meant by the term 'relative isotopic mass'. [1]

.....

.....

(ii) Calculate the relative atomic mass of cerium, giving your answer to **four** significant figures. You **must** show your method. [3]

$A_r(Ce)$ = ...

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(b) Some radioactive isotopes of cerium can be synthesized by nuclear reactions.

Radioisotope of cerium	Type of decay	Half-life
^{134}Ce	electron capture	3 days
^{139}Ce	electron capture	140 days
^{143}Ce	β^- emission	33 hours
^{144}Ce	β^- emission	280 days

(i) Identify the isotopes produced from ^{134}Ce and ^{143}Ce in their radioactive decay processes. [2]

Decay of ^{134}Ce

Element symbol ..... Mass number .....

Decay of ^{143}Ce

Element symbol ..... Mass number.....

(ii) One method of measuring the half-life of isotopes with half-lives of a few hours to a few days is to take a sample of known composition and record low resolution mass spectra at regular intervals to measure the height of the peaks of each mass.

Suggest why this method would not be suitable for any of these isotopes. [2]

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(iii) Another method of measuring the half-life is to measure the level of radioactivity over time.

An initial sample contained a mixture of equal amounts of ^{139}Ce and ^{144}Ce. After a period of storage, the β^- emission due to ^{144}Ce had dropped to 25% of its initial value.

By considering the decay of both isotopes, calculate the percentage of the cerium remaining that is ^{139}Ce. [3]

Percentage = ... %

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(c) Ce^{4+} ions can be used as oxidising agents in redox titrations, such as those involving the oxidation of Fe^{2+}.

$$Ce^{4+}(aq) + Fe^{2+}(aq) \longrightarrow Ce^{3+}(aq) + Fe^{3+}(aq)$$

(i) A titration requires 250 cm^3 of a standard solution of $Ce(SO_4)_2$ of concentration 0.200 $mol\,dm^{-3}$.

Describe how this standard solution could be produced. You should include the mass of $Ce(SO_4)_2$ that would be required. [6 QER]

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(ii) A sample of 0.680 g of an iron ore containing $FeCO_3$ as the only iron-containing compound was dissolved in a suitable acid. This was titrated against the standard $Ce^{4+}(aq)$ solution produced in part (i) and it required 22.45 cm^3 of the standard solution for complete reaction.

Calculate the mass of $FeCO_3$ present in the ore sample. [3]

Mass of $FeCO_3$ = ... g

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(iii) A separate ore contains both FeO and $FeCO_3$.

Explain why the method in part (ii) would **not** be suitable for finding the mass of $FeCO_3$ in this ore and outline a method that would be suitable. [3]

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(d) Ce^{4+} ions can be produced in solution by oxidation of Ce^{3+} ions.

Use the data below to identify suitable oxidising agent(s) for this process, giving your reasoning. [2]

	Standard electrode potential, E^{θ}/V
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.78
$Ce^{4+} + e^- \rightleftharpoons Ce^{3+}$	+1.61
$BrO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}Br_2 + 3H_2O$	+1.52
$ClO_4^- + 2H^+ + 2e^- \rightleftharpoons ClO_3^- + H_2O$	+1.23

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10. There are many organic acids produced by living things. These include citric acid in fruit and lactic acid produced during anaerobic respiration.

(a) A solution of citric acid is found to have a pH of 3.2. Calculate the concentration of H^+ ions in this solution. [1]

Concentration = ... $mol\,dm^{-3}$

(b) Citric acid is a tribasic acid, represented as H_3(citrate), as it contains three acidic hydrogen atoms in each molecule.

It reacts with sodium hydrogencarbonate in an endothermic reaction.

$$H_3(citrate)(aq) + 3NaHCO_3(s) \longrightarrow Na_3(citrate)(aq) + 3H_2O(l) + 3CO_2(g)$$

(i) Suggest why this reaction is feasible even though the reaction is endothermic. [2]

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(ii) A sample of 50.0 cm^3 of aqueous citric acid was treated with excess aqueous $NaHCO_3$ and the volume and temperature of the carbon dioxide gas produced was measured.

A total of 72.2 cm^3 of carbon dioxide was produced at a temperature of 16 °C and 1 atm pressure. Calculate the initial concentration of the aqueous citric acid. [3]

Concentration = ... $mol\,dm^{-3}$

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(iii) In a separate experiment, a student studies the enthalpy change during the reaction between aqueous citric acid and solid sodium hydrogencarbonate, $NaHCO_3$.

He follows the method below.

1. Measure 50.0 cm^3 of citric acid of concentration 0.500 mol dm^{-3} and place in a polystyrene cup with a lid.
2. Place a thermometer with 0.1 °C divisions through the lid of the cup and measure the temperature of the citric acid every 30 seconds for 3 minutes.
3. At 3 minutes add 2.300 g of powdered $NaHCO_3$ and mix thoroughly.
4. Measure the temperature every 30 seconds for a further 5 minutes.
5. Plot a graph of the data and use this to find the maximum temperature change.

I. Explain why the temperature is measured every 30 seconds for 3 minutes before adding the $NaHCO_3$. [1]

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.....

II. Explain why the temperature is measured every 30 seconds for 5 minutes after adding the $NaHCO_3$. [1]

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III. Calculate the number of moles of both citric acid and sodium hydrogencarbonate used in the experiment and hence show which is in excess. [3]

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IV. The maximum temperature change, ΔT, is found to be –2.3 °C.

Calculate the percentage error in this measurement. [1]

Percentage error = ... %

V. The experiment is repeated using different conditions to produce a larger temperature change. Using 25.0 cm^3 of 0.800 mol dm^{-3} citric acid solution and excess sodium hydrogencarbonate gives a temperature change of –10.1 °C.

Calculate the enthalpy change for the reaction. [3]

$$H_3(citrate) + 3NaHCO_3 \longrightarrow Na_3(citrate) + 3H_2O + 3CO_2$$

ΔH = ... kJ mol^{-1}

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(c) Lactic acid is a weak monobasic acid with a K_a of 1.40×10^{-4} mol dm^{-3}.

(i) Calculate the concentration of a lactic acid solution of pH 2.89. [2]

Concentration = ... mol dm^{-3}

(ii) A mixture of lactic acid and sodium lactate forms a buffer solution.

I. State what is meant by a 'buffer solution'. [1]

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II. Calculate the pH of a buffer solution formed by mixing 100 cm^3 of 0.20 mol dm^{-3} aqueous lactic acid with 50 cm^3 of 0.20 mol dm^{-3} aqueous sodium lactate. [3]

pH = ...

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11. Seawater contains a wide range of compounds formed from atoms of many different elements. The ten most abundant elements are shown in the table.

Element	Abundance / g dm^{-3}
oxygen	857
hydrogen	108
chlorine	19.4
sodium	10.8
magnesium	1.29
sulfur	0.905
calcium	0.412
potassium	0.399
bromine	0.0673
carbon	0.0281

(a) Seawater contains a range of oxyanions such as carbonate and sulfate which contain a small proportion of the oxygen atoms present.

Assuming all hydrogen atoms present are contained in water molecules, use the data in the table to calculate the percentage of the oxygen atoms that are present in water molecules. [2]

Percentage of oxygen atoms = ... %

Examiner only

(b) Flame tests can identify many of the metal ions present in seawater.

(i) Give the colours expected in flame tests for each of the metal ions present. [2]

sodium .....

magnesium .....

calcium .....

potassium .....

(ii) Suggest why flame tests are not always effective for identifying the metal ions present in **mixtures** like seawater. [1]

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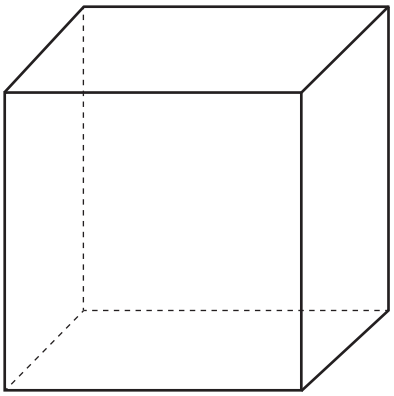
(c) It is possible to form crystals of sodium chloride by evaporation of seawater.

Complete and label the diagram below to show the crystal structure of sodium chloride. [2]



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(d) Evaporation of seawater can also form hydrated salts, $MX_n.aH_2O$, that include common ions formed from the elements listed in the table. One such salt has several different hydrated forms, including $a=6$, $a=4$ and $a=2$.

A sample of $MX_n.6H_2O$ is heated and loses 16.44% of its initial mass as it forms $MX_n.4H_2O$. Identify MX_n. You **must** show your working. [3]

Identity of salt .....

(e) Bubbling chlorine gas through seawater causes an orange colouration to appear as small amounts of $Br_2(aq)$ are formed.

(i) Write an ionic equation for this process. [1]

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(ii) Excess chlorine is bubbled through a sample of seawater and $0.0673\,g\,dm^{-3}$ of Br_2 is produced. Find the concentration of $Br_2(aq)$ in $mol\,dm^{-3}$. [1]

Concentration = ... $mol\,dm^{-3}$

Examiner only

(f) The carbon present in seawater exists as dissolved carbon dioxide, HCO_3^- ions and CO_3^{2-} ions. There are complex equilibria between these species, which can be simplified as follows.

$$CO_2(g) \rightleftharpoons CO_2(aq)$$

$$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

$$HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$$

These equilibria are important when discussing the effects of increased atmospheric carbon dioxide and climate change.

More carbon dioxide in the atmosphere can lead to a decrease in the pH of the oceans. This can cause problems for marine creatures that form shells out of carbonate minerals. Use the equilibria to explain why this is so. [3]

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12. A transition metal compound $[ML_n]X_2$ was analysed and the following observations were made.

Crystal structure	The compound contains an octahedral transition metal complex with anions X^- formed from single atoms.
Addition of sodium hydroxide solution and warming	A pungent-smelling gas is released that turns moist red litmus paper blue. A precipitate with an unfamiliar colour forms when the solution cools. This precipitate does not dissolve in excess sodium hydroxide.
Addition of concentrated sulfuric acid	Coloured fumes are released with a smell of rotten eggs.
Addition of ligand $H_2NCH_2CH_2NH_2$, represented by the abbreviation 'en'	A new complex is formed with formula $[M(en)_3]X_2$. The mass of this compound is 18.82% greater than the original compound.

(a) State which anions, X^-, are present in the compound, giving a reason for your answer. [2]

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(b) The compound forms a coloured precipitate when sodium hydroxide is added.

(i) Explain why transition metals form coloured compounds. [3]

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(ii) The precipitate does not dissolve when excess sodium hydroxide is added. State what information this provides about metal M. [1]

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(c) State which ligands, L, are present in the complex ion, giving a reason for your answer. [2]

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(d) State the value of n, the number of ligands present in the complex. [1]

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Examiner only

(e) Use the reaction with $H_2NCH_2CH_2NH_2$ to calculate M_r for $[ML_n]X_2$ and hence find the identity of the transition metal, M.

You **must** show your working. [3]

M_r = ...

M is .....

(f) Write the formula of the complex cation, $[ML_n]^{a+}$. [1]

.....

Examiner only

(g) The metal hydroxide produced on reaction with sodium hydroxide, $M(OH)_2$, decomposes on heating in a similar manner to the decomposition of Group 2 hydroxides.

(i) Write an equation for the thermal decomposition of $M(OH)_2$. [1]

.....

(ii) Give the trend in the thermal stability of the hydroxides in Group 2. [1]

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.....

(iii) The Group 2 metal carbonates also decompose upon heating.

Calculate the minimum temperature required to decompose $MgCO_3$. [2]

$$MgCO_3(s) \longrightarrow MgO(s) + CO_2(g) \qquad \Delta H^{\theta} = 117\,kJ\,mol^{-1}$$

$$\Delta S^{\theta} = 175\,J\,K^{-1}\,mol^{-1}$$

Temperature = ... K

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13. The elements of Group 5 react with hydrogen to form compounds of formula XH_3. Some information regarding the physical properties of these compounds is shown in the table.

Compound	Formula	Boiling temperature / °C	Solubility in water / g dm^{-3}
ammonia	NH_3	–33	470
phosphane	PH_3	–83	0.312
arsane	AsH_3	–63	0.710
stibane	SbH_3	–17	4.24

(a) Identify and explain the patterns seen in these physical properties. [6 QER]

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(b) Use VSEPR theory to predict the shape of the PH_3 molecule, giving reasons for your answer. [3]

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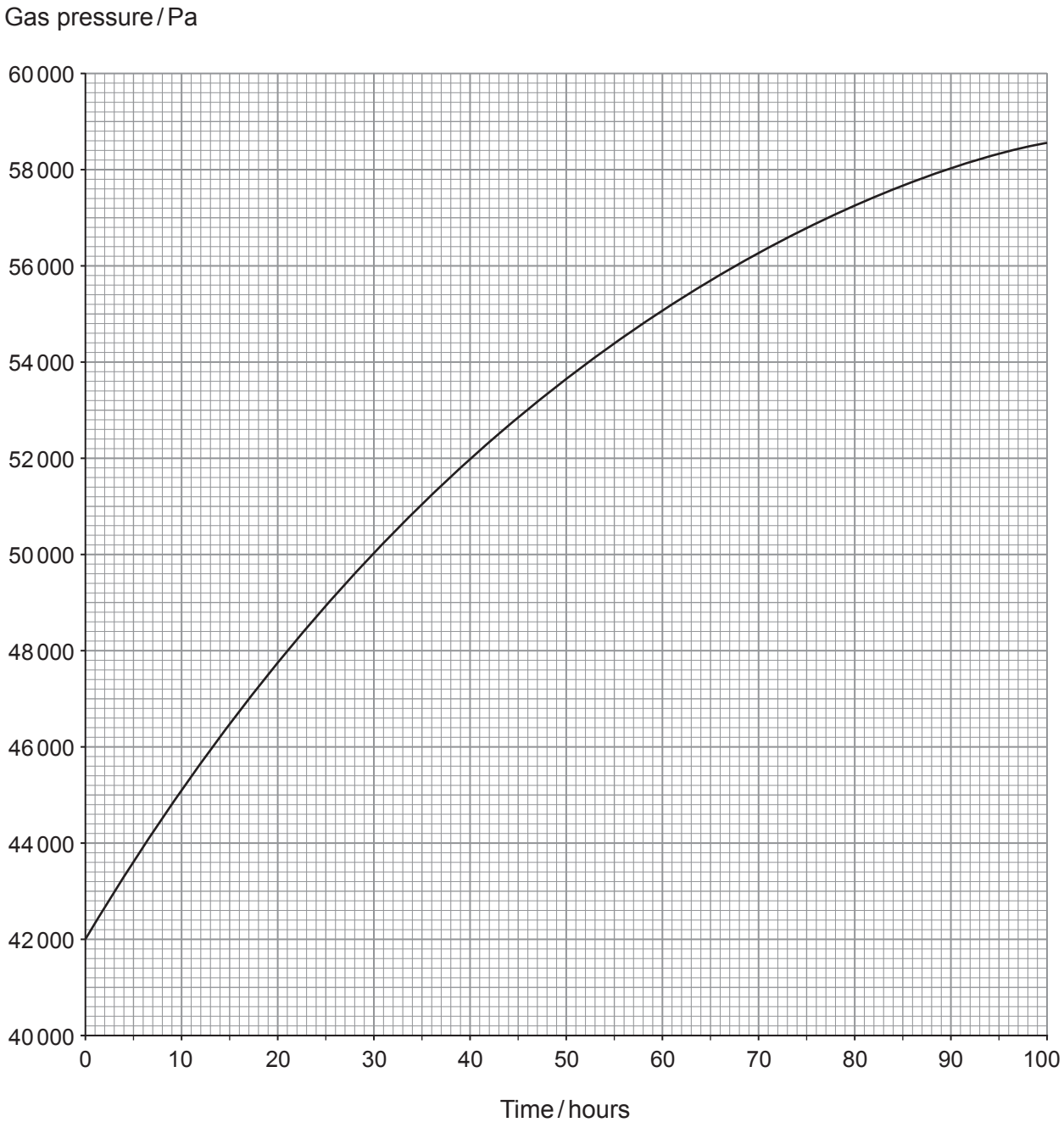
(c) Stibane is a gas that decomposes slowly at a temperature of 350 °C.

$$2SbH_3(g) \longrightarrow 2Sb(s) + 3H_2(g)$$

The decomposition of stibane was studied in a sealed vessel, with the pressure measured over a period of 100 hours. The results are shown on the graph.



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(i) The initial pressure in the vessel was 42 000 Pa. Calculate the pressure in the vessel when all the stibane had decomposed. [2]

Pressure = ... Pa

(ii) Calculate the initial rate of change of pressure in $Pa\,hr^{-1}$. [2]

Rate of change of pressure = ... $Pa\,hr^{-1}$

(iii) Use the initial pressure and your answer to part (i) to calculate the pressure in the vessel when half the stibane had decomposed.

Use this and the graph to show that the reaction is first order with respect to stibane. [4]

Pressure when half the stibane had decomposed = ... Pa

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Examiner only

(d) Ammonia is produced industrially using the Haber process.

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

The reaction traditionally used iron-based catalysts which reduce the activation energy of the reaction to 101.4 kJ mol^{-1}. Newer catalysts have been developed using ruthenium which reduce the activation energy further to 64.0 kJ mol^{-1}.

(i) These are examples of heterogeneous catalysts.

State what is meant by a 'heterogeneous' catalyst. [1]

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(ii) State, giving a reason, the effect of changing the catalyst on the position of this equilibrium. [2]

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(iii) The Haber process typically uses a temperature of 500 °C.

Replacing the iron-based catalyst with a newer ruthenium-based catalyst increases the initial rate of reaction by a factor, **f**, at this temperature.

Use the Arrhenius equation to calculate the value of **f**.

You may assume that the frequency factor in both cases is the same. [3]

f = ...

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(e) When water is added to gaseous phosphane no visible reaction occurs. However, studies using isotopes of hydrogen have shown that hydrogen atoms are exchanged between the phosphane and water.

The following gas phase equilibrium occurs, where D represents deuterium, a hydrogen isotope with a mass number of 2.

$$PH_2D(g) + H_2O(g) \rightleftharpoons PH_3(g) + HDO(g)$$

A sealed vessel of volume 500 cm^3 contained 1.00×10^{-3} mol of $PH_2D(g)$. A sample of 4.90×10^{-4} mol of $H_2O(g)$ was added and the mixture allowed to reach equilibrium.

The mass spectrum of the equilibrium mixture shows that 36% of the phosphorus is present in PH_3 and 64% of the phosphorus is present in PH_2D.

Calculate the value of the equilibrium constant K_c for this reaction. [4]

K_c = ...

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END OF PAPER

Question number	Additional page, if required. Write the question number(s) in the left-hand margin.

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Question number	Additional page, if required. Write the question number(s) in the left-hand margin.

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GCE A LEVEL

A410U10-1A

Z22-A410U10-1A

MONDAY, 13 JUNE 2022 – MORNING

CHEMISTRY – A level component 1
Data Booklet

Avogadro constant	N_A	$= 6.02 \times 10^{23}\ \text{mol}^{-1}$
molar gas constant	R	$= 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
molar gas volume at 273 K and 1 atm	V_m	$= 22.4\ \text{dm}^3\ \text{mol}^{-1}$
molar gas volume at 298 K and 1 atm	V_m	$= 24.5\ \text{dm}^3\ \text{mol}^{-1}$
Planck constant	h	$= 6.63 \times 10^{-34}\ \text{J s}$
speed of light	c	$= 3.00 \times 10^{8}\ \text{m s}^{-1}$
density of water	d	$= 1.00\ \text{g cm}^{-3}$
specific heat capacity of water	c	$= 4.18\ \text{J g}^{-1}\ \text{K}^{-1}$
ionic product of water at 298 K	K_w	$= 1.00 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$
fundamental electronic charge	e	$= 1.60 \times 10^{-19}\ \text{C}$

temperature (K) = temperature (°C) + 273

$1\ \text{dm}^3 = 1000\ \text{cm}^3$
$1\ \text{m}^3 = 1000\ \text{dm}^3$
1 tonne = 1000 kg
$1\ \text{atm} = 1.01 \times 10^5\ \text{Pa}$

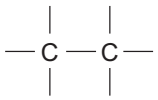
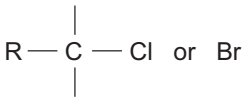
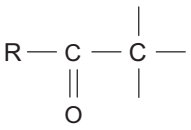
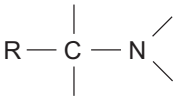
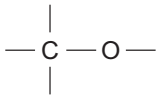
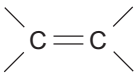
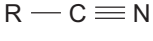
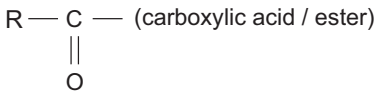
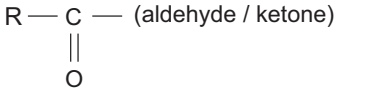
Multiple	Prefix	Symbol
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m

Multiple	Prefix	Symbol
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G

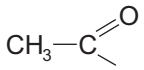
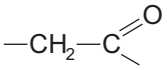
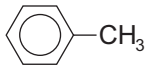
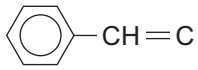
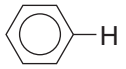
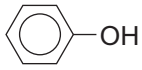
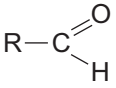
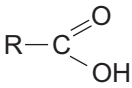
Infrared absorption values

Bond	Wavenumber / cm^{-1}
C — Br	500 to 600
C — Cl	650 to 800
C — O	1000 to 1300
C = C	1620 to 1670
C = O	1650 to 1750
C ≡ N	2100 to 2250
C — H	2800 to 3100
O — H (carboxylic acid)	2500 to 3200 (very broad)
O — H (alcohol / phenol)	3200 to 3550 (broad)
N — H	3300 to 3500

^{13}C NMR chemical shifts relative to TMS = 0

Type of carbon	Chemical shift, δ (ppm)
	5 to 40
	10 to 70
	20 to 50
	25 to 60
	50 to 90
	90 to 150
	110 to 125
	110 to 160
	160 to 185
	190 to 220

^{1}H NMR chemical shifts relative to TMS = 0

Type of proton	Chemical shift, δ (ppm)
$-CH_3$	0.1 to 2.0
$R-CH_3$	0.9
$R-CH_2-R$	1.3
$CH_3-C\equiv N$	2.0
	2.0 to 2.5
	2.0 to 3.0
	2.2 to 2.3
HC — Cl or HC — Br	3.1 to 4.3
HC — O	3.3 to 4.3
R — OH	4.5 *
— C = CH	4.5 to 6.3
— C = CH — CO	5.8 to 6.5
	6.5 to 7.5
	6.5 to 8.0
	7.0 *
	9.8 *
	11.0 *

*variable figure dependent on concentration and solvent

THE PERIODIC TABLE