



ANNUAL EXAMINATION 2023

FORM V CHEMISTRY

General Instructions

- Write using black pen.
- Remove centre staple and hand in all parts of the paper in a neat bundle.
- Write your candidate number in the space provided on pages 9, 13, 19 and 23.

Structure of Paper

- Section 1: Multiple Choice (15 marks).
Spend about 15 minutes on this section.
- Section 2: Extended response (75 marks).
Spend about 1 hour and 45 minutes on this section.

Friday 1 September

8:40am

Working Time: 2 hours

Total marks: 90

Checklist

Each boy should have the following:

- 1 Examination paper (data sheet attached at the back of paper)
- 1 Multiple choice answer sheet

JLS

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Section 1: Multiple Choice

15 marks

Attempt ALL Questions

Allow about 15 minutes to complete this section.

1 Which of the following techniques can be used to separate an insoluble salt from water?

- (A) Filtration
- (B) Distillation
- (C) Centrifugation
- (D) Visual inspection

2 How many hydrogen atoms are present in a sample containing 0.10 mol of ammonium hydrogencarbonate?

- (A) 6.0×10^{22}
- (B) 1.8×10^{23}
- (C) 2.4×10^{23}
- (D) 3.0×10^{23}

3 Which of the following processes is exothermic?

- (A) $I_2(s) \rightarrow I_2(l)$
- (B) $H_2O(l) \rightarrow H_2O(s)$
- (C) $NH_3(l) \rightarrow NH_3(g)$
- (D) $CO_2(s) \rightarrow CO_2(g)$

- 4 Consider the specific heat capacity of the following metals.

Metal	Specific heat capacity / J kg ⁻¹ K ⁻¹
Ag	234
Au	130
Cu	385
Pt	134

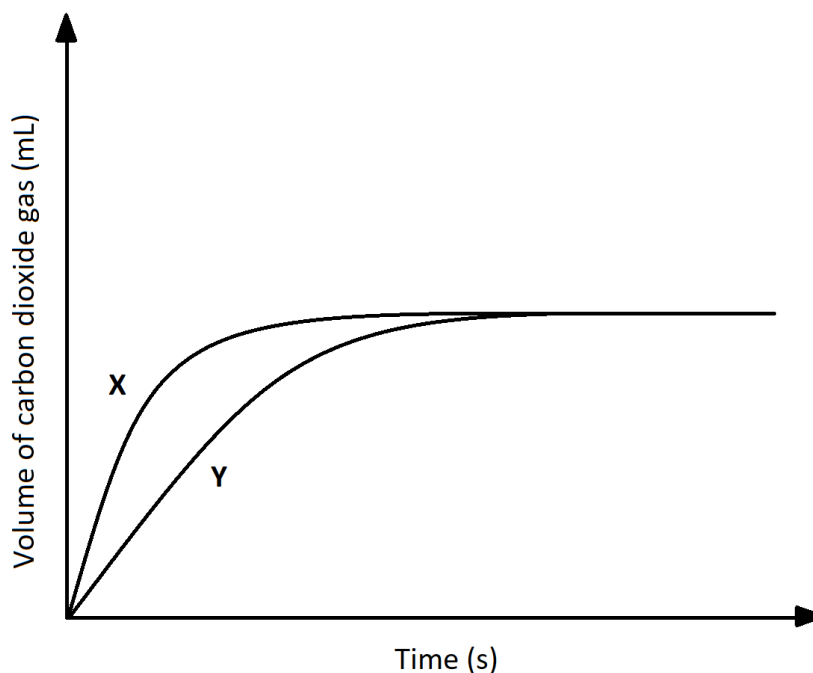
Which metal will show the greatest temperature increase if 50 J of heat is supplied to a 0.001 kg sample of each metal at the same initial temperature.

- (A) Ag
(B) Au
(C) Cu
(D) Pt
- 5 Which of the following factors will influence the collision energy of reacting particles in solution.
- (A) Activation energy
(B) A catalyst
(C) Concentration
(D) Temperature
- 6 Which of the following statements about molecules is true?
- (A) Atoms in molecules are held together by strong intermolecular forces.
(B) There are molecules of NaCl in a salt crystal.
(C) Molecules contain two or more elements.
(D) Non-polar molecules may have polar bonds.

- 7 Which of the following periodic trends are true for the halogens as you go down the group.
- (A) Reactivity increases and electronegativity increases.
 - (B) Reactivity increases and electron affinity decreases.
 - (C) Reactivity decreases and electronegativity decreases.
 - (D) Reactivity decreases and electron affinity increases.
- 8 What mass of lead(II) bromide is produced when 20.0 mL of 0.400 mol L⁻¹ sodium bromide reacts with 30.0 mL of 0.400 mol L⁻¹ lead(II) nitrate solution?
- (A) 1.47 g
 - (B) 2.94 g
 - (C) 4.40 g
 - (D) 8.81 g
- 9 Which reaction equation best corresponds to the value for the standard enthalpy of formation of potassium oxide?
- (A) $4\text{K}(g) + \text{O}_2(g) \rightarrow 2\text{K}_2\text{O}(g)$
 - (B) $2\text{K}(g) + \text{O}(g) \rightarrow \text{K}_2\text{O}(g)$
 - (C) $2\text{K}(s) + 0.5\text{O}_2(g) \rightarrow \text{K}_2\text{O}(s)$
 - (D) $4\text{K}(s) + \text{O}_2(g) \rightarrow 2\text{K}_2\text{O}(s)$

- 10 A student investigates the rate of reaction between solid calcium carbonate and an excess of 1.0 mol L^{-1} hydrochloric acid.

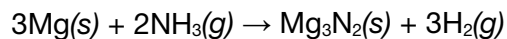
The experiment was performed twice, using two different sets of conditions, **X** and **Y**, and the volume of gas collected was measured over time.



From the graph, which of the following set of conditions could be true for **X** and **Y**?

	Conditions X		Conditions Y	
(A)	Large chunks of $\text{CaCO}_3(\text{s})$	25°C	Powdered $\text{CaCO}_3(\text{s})$	25°C
(B)	Powdered $\text{CaCO}_3(\text{s})$	25°C	Powdered $\text{CaCO}_3(\text{s})$	35°C
(C)	Large chunks of $\text{CaCO}_3(\text{s})$	35°C	Large chunks of $\text{CaCO}_3(\text{s})$	25°C
(D)	Large chunks of $\text{CaCO}_3(\text{s})$	35°C	Powdered $\text{CaCO}_3(\text{s})$	35°C

- 11** Magnesium reacts with ammonia to produce magnesium nitride and hydrogen, according to the following equation:



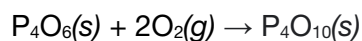
Calculate the volume of ammonia (measured at 1200 K and 500 kPa) required to react with 50.0 g of magnesium.

- (A) 20.5 L
(B) 27.4 L
(C) 41.0 L
(D) 61.6 L
- 12** Lithium aluminium hydride reacts violently with water, by releasing lots of heat and producing a flame. Which of the following statements about the reaction between lithium aluminium hydride and water must be true.
- (A) The activation energy for this reaction must be very high.
(B) The reaction must be highly endothermic.
(C) The total energy of the products must be much higher than the energy level of the reactants.
(D) The value for ΔH is large and negative.
- 13** Which of the following compounds contains 11.44% phosphorus by mass?
- (A) PF_3
(B) PCl_3
(C) PCl_5
(D) PBr_3

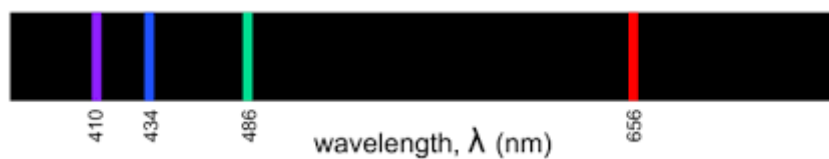
- 14 The standard enthalpy change of formation of two oxides of phosphorus are:



What is the enthalpy change, in kJ mol^{-1} , for the reaction below?



- (A) +4600
(B) +1400
(C) -1400
(D) -4600
- 15 Below is an **emission** spectrum for an element.



What do each of the lines correspond to?

- (A) The energy released when an electron drops from a higher energy level to a lower one.
(B) The energy absorbed when an electron climbs from a lower energy level to a higher one.
(C) The energy required to remove successive electrons from the valence shell.
(D) The energy of all its electrons.

Section 2: Extended Response

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CANDIDATE NUMBER

75 marks

Attempt ALL Questions

Allow about 1 hour 45 minutes to complete this section.

Question 16 (4 marks)

Marks

Write balanced chemical equations for the following reactions.

a) The reaction between sodium and phosphoric acid.

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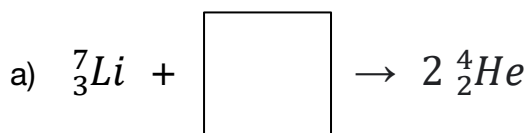
b) The reaction between lead(II) nitrate and sodium hydroxide.

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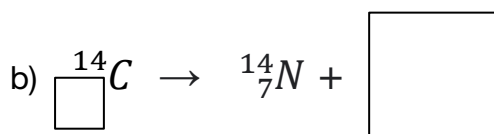
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Question 17 (3 marks)

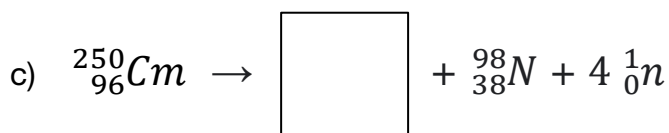
Complete each of the following nuclear equations.



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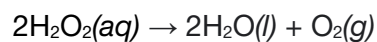
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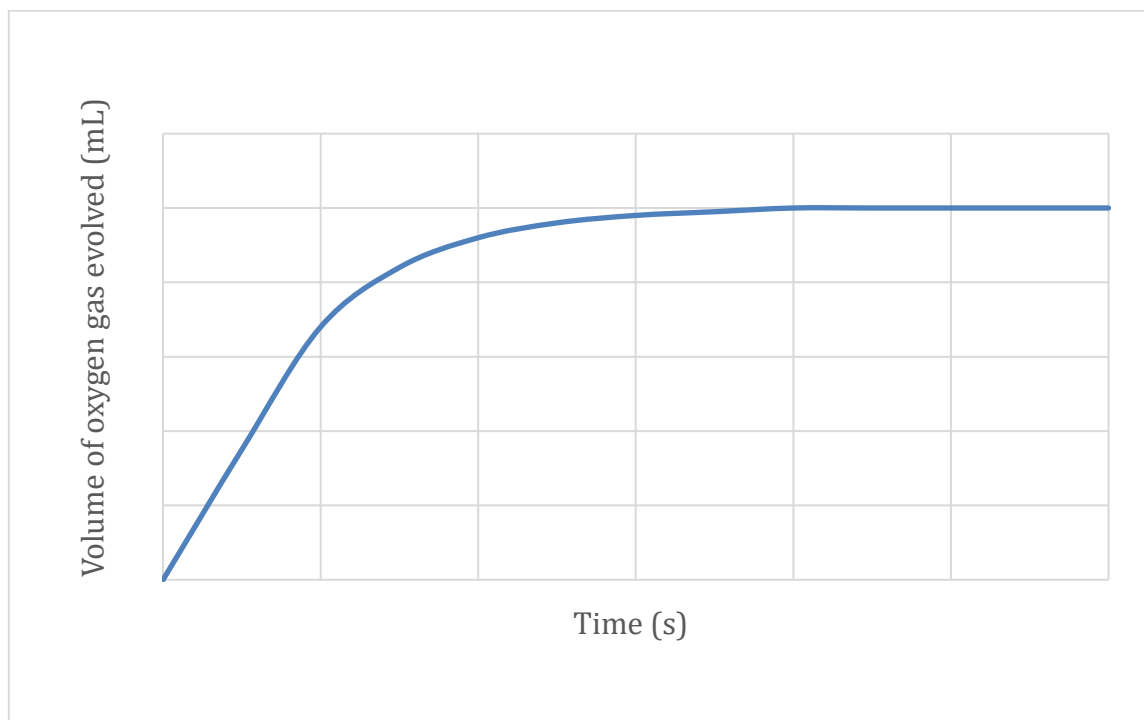
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Question 18 (4 marks)**Marks**

Hydrogen peroxide decomposes to produce oxygen gas.



The graph shows the volume of oxygen gas evolved when 50 mL of 1.0 mol L⁻¹ hydrogen peroxide decomposes at 298 K.



On the graph above, sketch how the volume of oxygen gas evolved would change if the experiment was repeated at 298 K using the following:

a) 25 mL of 2.0 mol L⁻¹ hydrogen peroxide. Label this curve A.

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b) 25 mL of 1.0 mol L⁻¹ hydrogen peroxide in the presence of a manganese dioxide catalyst. Label this curve B.

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Question 19 (4 marks)**Marks**

Calculate the volume of $0.2503 \text{ mol L}^{-1}$ potassium iodide solution required for complete reaction with 25.00 mL of $0.2042 \text{ mol L}^{-1}$ lead(II) acetate solution.

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Question 20 (6 marks)

Compound **X**, a common solvent, contains 62.04% carbon and 27.55% oxygen by mass, with the remainder being hydrogen.

- a) Calculate the empirical formula for compound **X**.

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A 250 mL flask containing 0.6038 g of compound **X** has a pressure of 101.3 kPa and a temperature of 293.0 K.

- b) Calculate the molar mass of compound **X**, and hence its molecular formula.

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Question 21 (4 marks)

Marks

Dinitrogen monoxide, $\text{N}_2\text{O}(g)$, is used as a rocket fuel. The data in the table below shows how the activation energy, E_A , for the decomposition of dinitrogen monoxide in the presence of different catalysts.



Conditions	E_A (kJ mol ⁻¹)
no catalyst	245
gold catalyst	121
iron catalyst	116
platinum catalyst	136

a) Use the table to identify the most effective catalyst for this decomposition.

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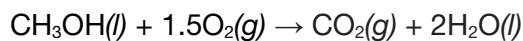
b) Explain how this catalyst affects the rate of N_2O decomposition in terms of Collision Theory.

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Question 22 (8 marks)**Marks**

Two students, John and Marit, were asked to determine the value for the enthalpy of combustion, $\Delta_c H^\ominus$, of methanol ($\text{CH}_3\text{OH}(l)$).



John used the average bond enthalpies given in the table below.

Bond	Average bond enthalpies (kJ mol^{-1})
C – H	413
C – O	358
O – H	463
O = O	495
C = O	804

- a) Calculate the value for the enthalpy of combustion of methanol obtained by John using the average bond enthalpies given in the table above.

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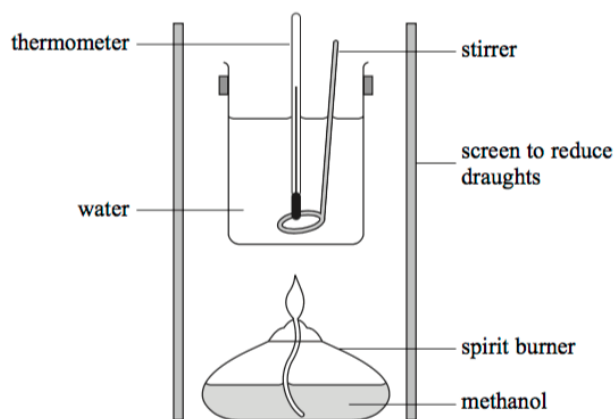
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Question 22 continued.

Marks

Marit placed a beaker containing 100 mL of water above a spirit burner containing methanol ($\text{CH}_3\text{OH}(l)$) as shown in the diagram below. She weighed the spirit burner and measured the initial temperature of the water.



Marit lit the spirit burner and waited until the temperature had increased significantly. She weighed the spirit burner again, measured the final temperature of the water and placed all her results into the table below.

Initial mass of spirit burner and methanol	52.550 g
Final mass of spirit burner and methanol	52.268 g
Initial temperature of water	20.1°C
Final temperature of water	30.4°C

b) Calculate the value for the enthalpy of combustion determined by Marit using calorimetry.

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Question 22 continued.**Marks**

The literature value for the standard enthalpy of combustion of methanol is -726 kJ mol^{-1} .

- c) Explain why John obtained a result closer to the literature value for the enthalpy of combustion of methanol than Marit.

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- d) Explain why there is still a difference between John's result and the literature value for the enthalpy of combustion of methanol.

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Question 23 (5 marks)**Marks**

Orica produces sodium cyanide (NaCN) at its plant in Yarwun, Queensland. It is supplied to the mining industry in tanks containing 24 200 kg of a 30.0%(w/w) aqueous solution.

- a) Calculate the mass of sodium cyanide present in each tank.

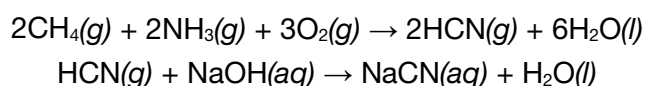
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Sodium cyanide is prepared in a two-step process, with the main starting materials being methane, ammonia and sodium hydroxide.



- b) Calculate the mass of ammonia required to produce the mass of sodium cyanide in part (a).

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- c) Calculate the volume (measured at 25°C and 100 kPa) of oxygen gas required to produce the mass of sodium cyanide in part (a).

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Question 24 (6 marks)**Marks**

The fluoride ion and the magnesium ion have the same electron configuration.

- a) Write the electron configuration for the two ions using spdf notation.

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- b) State which of the two ions would have a greater ionic radius and explain your choice.

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- c) The successive ionisation energies of magnesium are given in the table below.

Ionisation	Ionisation energy (kJ mol ⁻¹)
1	738
2	1451
3	7733

By referencing this data, explain why magnesium forms a Mg²⁺ ion and not a Mg³⁺ ion.

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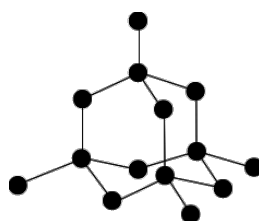
CANDIDATE NUMBER

Question 25 (5 marks)

Marks

Carbon can be found in a variety of forms.

Diamond, an allotrope of carbon, is the hardest naturally occurring substance on Earth.



Structure of diamond

a) Explain why diamond is such a hard material in terms of structure and bonding.

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Metal carbides are also hard materials used in computing and machinery.

b) Draw the Lewis dot structure for the carbide ion (C_2^{2-}).

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Question 26 (5 marks)**Marks**

Phosphorus trifluoride, PF_3 , is a colourless and odourless gas.

- a) Deduce whether phosphorus trifluoride will be a polar molecule or not and explain your reasoning.

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- b) Name the predominant intermolecular force that exists between phosphorus trifluoride molecules and explain how this force arises.

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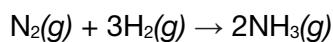
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Question 27 (9 marks)**Marks**

The production of ammonia is an important reaction in industry.



Some thermodynamic data has been given in the table below.

	$\text{N}_2(\text{g})$	$\text{H}_2(\text{g})$	$\text{NH}_3(\text{g})$
$\Delta_f H^\ominus$ (kJ mol ⁻¹)	0	0	-41
S^\ominus (J K ⁻¹ mol ⁻¹)	193	131	192

a) Calculate the standard enthalpy change for the reaction.

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b) Calculate the standard entropy change for the reaction.

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c) Calculate ΔG for the reaction at 300 K and determine whether the reaction will be spontaneous at this temperature.

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Question continues on next page.

Question 27 continued.**Marks**

- d) If ammonia was produced as a liquid and not a gas in this reaction, state and explain how the values for ΔH and ΔS would change.

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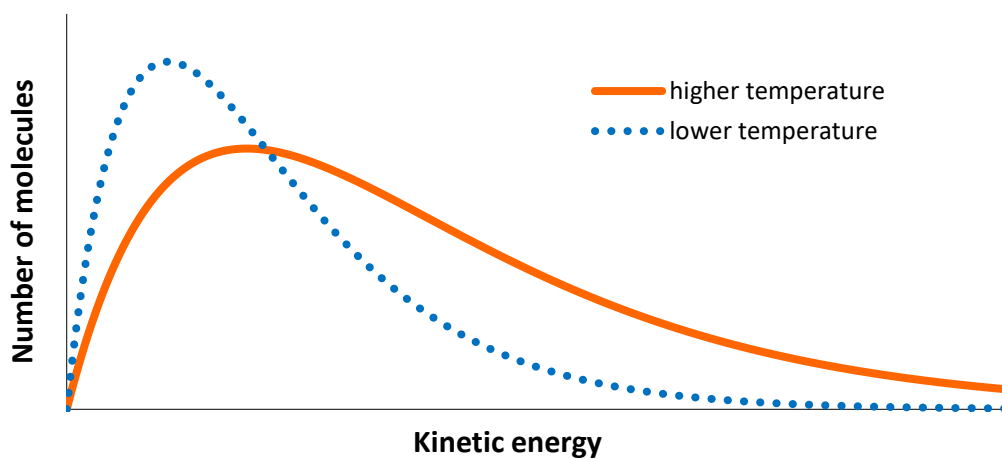
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Question 28 (3 marks)

Marks

The Maxwell Boltzmann distribution below shows an energy distribution of a gaseous substance at two different temperatures.



Use the distribution above to explain why increasing the temperature significantly increases the rate of a chemical reaction.

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Question 29 (4 marks)**Marks**Calculate the bond enthalpy of a C≡O bond in kJ mol^{-1} using the data given below.

Bond enthalpy of O=O bond

$$\Delta H^\ominus = +495 \text{ kJ mol}^{-1}$$

Enthalpy of formation of $\text{CO}_2(\text{g})$

$$\Delta H^\ominus = -394 \text{ kJ mol}^{-1}$$

 $\text{C}(\text{s}) \rightarrow \text{C}(\text{g})$

$$\Delta H^\ominus = +716 \text{ kJ mol}^{-1}$$

 $2\text{CO}_2(\text{g}) \rightarrow \text{O}_2(\text{g}) + 2\text{CO}(\text{g})$

$$\Delta H^\ominus = +566 \text{ kJ mol}^{-1}$$

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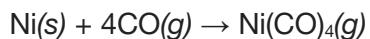
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Question 30 (5 marks)**Marks**

The Mond process is used to purify nickel, by reacting impure nickel with carbon monoxide:



Impure nickel is placed in a 100 L reactor and the reactor pressurised with carbon monoxide gas. The initial pressure in the reactor is 215 kPa and the initial temperature is 295 K. After the mixture in the reactor is heated the reaction takes place. The final pressure in the reactor is 145 kPa and the final temperature is 350 K. Calculate the mass of nickel consumed in this reaction, assuming that the only reaction occurring is shown in the equation above.

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END OF EXAMINATION

Chemistry

FORMULAE SHEET

$$n = \frac{m}{MM}$$

$$q = mC\Delta T$$

$$pK_a = -\log_{10}[K_a]$$

$$c = \frac{n}{v}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$A = \epsilon lc = \log_{10} \frac{I_0}{I}$$

$$PV = nRT$$

$$\text{pH} = -\log_{10}[\text{H}^+]$$

Avogadro constant, N_A $6.022 \times 10^{23} \text{ mol}^{-1}$

Volume of 1 mole ideal gas: at 100 kPa and

at 0°C (273.15 K) 22.71 L

at 25°C (298.15 K) 24.79 L

Gas constant $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

Ionisation constant for water at 25°C (298.15 K), K_w 1.0×10^{-14}

Specific heat capacity of water $4.18 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

DATA SHEET

Solubility constants at 25°C

Compound	K_{sp}	Compound	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	Lead(II) hydroxide	1.43×10^{-15}
Calcium hydroxide	5.02×10^{-6}	Lead(II) phosphate	8.0×10^{-43}
Calcium phosphate	2.07×10^{-29}	Lead(II) sulfate	2.53×10^{-8}
Calcium sulfate	4.93×10^{-5}	Magnesium carbonate	6.82×10^{-6}
Copper(II) carbonate	1.4×10^{-10}	Magnesium hydroxide	5.61×10^{-12}
Copper(II) hydroxide	2.2×10^{-20}	Magnesium phosphate	1.04×10^{-24}
Copper(II) phosphate	1.40×10^{-37}	Silver bromide	5.35×10^{-13}
Iron(II) carbonate	3.13×10^{-11}	Silver chloride	1.77×10^{-10}
Iron(II) hydroxide	4.87×10^{-17}	Silver carbonate	8.46×10^{-12}
Iron(III) hydroxide	2.79×10^{-39}	Silver hydroxide	2.0×10^{-8}
Iron(III) phosphate	9.91×10^{-16}	Silver iodide	8.52×10^{-17}
		Silver phosphate	8.89×10^{-17}
		Silver sulfate	1.20×10^{-5}

Aylward and Findlay, *SI Chemical Data* (5th Edition) is the principal source of data for this examination paper. Some data may have been modified for examination purposes.

Some standard potentials

$\text{K}^+ + \text{e}^-$	\rightleftharpoons	$\text{K}(s)$	-2.94 V
$\text{Ba}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ba}(s)$	-2.91 V
$\text{Ca}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ca}(s)$	-2.87 V
$\text{Na}^+ + \text{e}^-$	\rightleftharpoons	$\text{Na}(s)$	-2.71 V
$\text{Mg}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Mg}(s)$	-2.36 V
$\text{Al}^{3+} + 3\text{e}^-$	\rightleftharpoons	$\text{Al}(s)$	-1.68 V
$\text{Mn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Mn}(s)$	-1.18 V
$\text{H}_2\text{O} + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(g) + \text{OH}^-$	-0.83 V
$\text{Zn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Zn}(s)$	-0.76 V
$\text{Fe}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Fe}(s)$	-0.44 V
$\text{Ni}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ni}(s)$	-0.24 V
$\text{Sn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Sn}(s)$	-0.14 V
$\text{Pb}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Pb}(s)$	-0.13 V
$\text{H}^+ + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(g)$	0.00 V
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$\text{SO}_2(aq) + 2\text{H}_2\text{O}$	0.16 V
$\text{Cu}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Cu}(s)$	0.34 V
$\frac{1}{2}\text{O}_2(g) + \text{H}_2\text{O} + 2\text{e}^-$	\rightleftharpoons	2OH^-	0.40 V
$\text{Cu}^+ + \text{e}^-$	\rightleftharpoons	$\text{Cu}(s)$	0.52 V
$\frac{1}{2}\text{I}_2(s) + \text{e}^-$	\rightleftharpoons	I^-	0.54 V
$\frac{1}{2}\text{I}_2(aq) + \text{e}^-$	\rightleftharpoons	I^-	0.62 V
$\text{Fe}^{3+} + \text{e}^-$	\rightleftharpoons	Fe^{2+}	0.77 V
$\text{Ag}^+ + \text{e}^-$	\rightleftharpoons	$\text{Ag}(s)$	0.80 V
$\frac{1}{2}\text{Br}_2(l) + \text{e}^-$	\rightleftharpoons	Br^-	1.08 V
$\frac{1}{2}\text{Br}_2(aq) + \text{e}^-$	\rightleftharpoons	Br^-	1.10 V
$\frac{1}{2}\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	H_2O	1.23 V
$\frac{1}{2}\text{Cl}_2(g) + \text{e}^-$	\rightleftharpoons	Cl^-	1.36 V
$\frac{1}{2}\text{Cr}_2\text{O}_7^{2-} + 7\text{H}^+ + 3\text{e}^-$	\rightleftharpoons	$\text{Cr}^{3+} + \frac{7}{2}\text{H}_2\text{O}$	1.36 V
$\frac{1}{2}\text{Cl}_2(aq) + \text{e}^-$	\rightleftharpoons	Cl^-	1.40 V
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^-$	\rightleftharpoons	$\text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.51 V
$\frac{1}{2}\text{F}_2(g) + \text{e}^-$	\rightleftharpoons	F^-	2.89 V

BACK OF PERIODIC TABLE

PERIODIC TABLE OF THE ELEMENTS

		KEY																																																																																							
Atomic Number	Symbol	Atomic Number	Symbol	Atomic Number	Symbol	Atomic Number	Symbol	Atomic Number	Symbol	Atomic Number	Symbol																																																																														
Standard Atomic Weight	Name	Standard Atomic Weight	Name	Standard Atomic Weight	Name	Standard Atomic Weight	Name	Standard Atomic Weight	Name	Standard Atomic Weight	Name																																																																														
1 H 1.008 Hydrogen	2 He 4.003 Helium	3 Li 6.941 Lithium	4 Be 9.012 Beryllium	5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon	11 Na 22.99 Sodium	12 Mg 24.31 Magnesium	13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon	19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton	37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc 99.91 Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon	55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57-71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po 209.0 Polonium	85 At 210.0 Astatine	86 Rn 222.0 Radon	87 Fr 223.0 Francium	88 Ra 226.0 Radium	89-103 Actinoids	104 Rf 261.0 Rutherfordium	105 Db 262.0 Dubnium	106 Sg 263.0 Seaborgium	107 Bh 264.0 Bohrium	108 Hs 265.0 Hassium	109 Mt 268.0 Meitnerium	110 Ds 271.0 Darmstadtium	111 Rg 272.0 Roentgenium	112 Cn 285.0 Copernicium	113 Nh 284.0 Nihonium	114 Fl 289.0 Flerovium	115 Mc 288.0 Moscovium	116 Lv 293.0 Livermorium	117 Ts 289.0 Tennessine	118 Og 294.0 Oganesson

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm 144.9 Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium
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Actinoids

89 Ac 232.0 Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np 237.0 Neptunium	94 Pu 244.0 Plutonium	95 Am 243.0 Americium	96 Cm 247.0 Curium	97 Bk 247.0 Berkelium	98 Cf 251.0 Californium	99 Es 252.0 Einsteinium	100 Fm 257.0 Fermium	101 Md 258.0 Mendelevium	102 No 259.0 Nobelium	103 Lr 260.0 Lawrencium
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Standard atomic weights are abridged to four significant figures.

Elements with no reported values in the table have no stable nuclides.

Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (November 2016 version). The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

Section 1: Multiple Choice

15 marks

Attempt ALL Questions

Allow about 15 minutes to complete this section.

1 Which of the following techniques can be used to separate an insoluble salt from water?

- (A) Filtration
- (B) Distillation
- (C) Centrifugation
- (D) Visual inspection

2 How many hydrogen atoms are present in a sample containing 0.10 mol of ammonium hydrogencarbonate?

- (A) 6.0×10^{22}
- (B) 1.8×10^{23}
- (C) 2.4×10^{23}
- (D) 3.0×10^{23}

3 Which of the following processes is exothermic?

- (A) $I_2(s) \rightarrow I_2(l)$
- (B) $H_2O(l) \rightarrow H_2O(s)$
- (C) $NH_3(l) \rightarrow NH_3(g)$
- (D) $CO_2(s) \rightarrow CO_2(g)$

- 4 Consider the specific heat capacity of the following metals.

Metal	Specific heat capacity / J kg ⁻¹ K ⁻¹
Ag	234
Au	130
Cu	385
Pt	134

Which metal will show the greatest temperature increase if 50 J of heat is supplied to a 0.001 kg sample of each metal at the same initial temperature.

- (A) Ag
(B) Au
(C) Cu
(D) Pt
- 5 Which of the following factors will influence the collision energy of reacting particles in solution.
- (A) Activation energy
(B) A catalyst
(C) Concentration
(D) Temperature
- 6 Which of the following statements about molecules is true?
- (A) Atoms in molecules are held together by strong intermolecular forces.
(B) There are molecules of NaCl in a salt crystal.
(C) Molecules contain two or more elements.
(D) Non-polar molecules may have polar bonds.

7 Which of the following periodic trends are true for the halogens as you go down the group.

- (A) Reactivity increases and electronegativity increases.
- (B) Reactivity increases and electron affinity decreases.
- (C) Reactivity decreases and electronegativity decreases.
- (D) Reactivity decreases and electron affinity increases.

8 What mass of lead(II) bromide is produced when 20.0 mL of 0.400 mol L⁻¹ sodium bromide reacts with 30.0 mL of 0.400 mol L⁻¹ lead(II) nitrate solution?

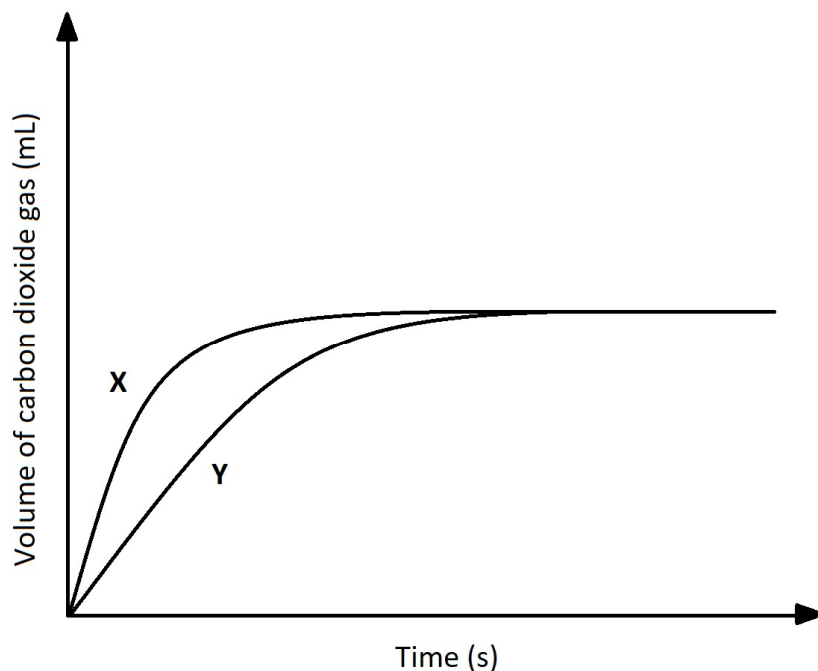
- (A) 1.47 g
- (B) 2.94 g
- (C) 4.40 g
- (D) 8.81 g

9 Which reaction equation best corresponds to the value for the standard enthalpy of formation of potassium oxide?

- (A) $4\text{K}(g) + \text{O}_2(g) \rightarrow 2\text{K}_2\text{O}(g)$
- (B) $2\text{K}(g) + \text{O}(g) \rightarrow \text{K}_2\text{O}(g)$
- (C) $2\text{K}(s) + 0.5\text{O}_2(g) \rightarrow \text{K}_2\text{O}(s)$
- (D) $4\text{K}(s) + \text{O}_2(g) \rightarrow 2\text{K}_2\text{O}(s)$

- 10 A student investigates the rate of reaction between solid calcium carbonate and an excess of 1.0 mol L^{-1} hydrochloric acid.

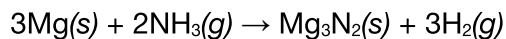
The experiment was performed twice, using two different sets of conditions, **X** and **Y**, and the volume of gas collected was measured over time.



From the graph, which of the following set of conditions could be true for **X** and **Y**?

	Conditions X		Conditions Y	
(A)	Large chunks of $\text{CaCO}_3(\text{s})$	25°C	Powdered $\text{CaCO}_3(\text{s})$	25°C
(B)	Powdered $\text{CaCO}_3(\text{s})$	25°C	Powdered $\text{CaCO}_3(\text{s})$	35°C
(C)	Large chunks of $\text{CaCO}_3(\text{s})$	35°C	Large chunks of $\text{CaCO}_3(\text{s})$	25°C
(D)	Large chunks of $\text{CaCO}_3(\text{s})$	35°C	Powdered $\text{CaCO}_3(\text{s})$	35°C

- 11** Magnesium reacts with ammonia to produce magnesium nitride and hydrogen, according to the following equation:



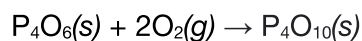
Calculate the volume of ammonia (measured at 1200 K and 500 kPa) required to react with 50.0 g of magnesium.

- (A) 20.5 L
(B) 27.4 L
(C) 41.0 L
(D) 61.6 L
- 12** Lithium aluminium hydride reacts violently with water, by releasing lots of heat and producing a flame. Which of the following statements about the reaction between lithium aluminium hydride and water must be true.
- (A) The activation energy for this reaction must be very high.
(B) The reaction must be highly endothermic.
(C) The total energy of the products must be much higher than the energy level of the reactants.
(D) The value for ΔH is large and negative.
- 13** Which of the following compounds contains 11.44% phosphorus by mass?
- (A) PF_3
(B) PCl_3
(C) PCl_5
(D) PBr_3

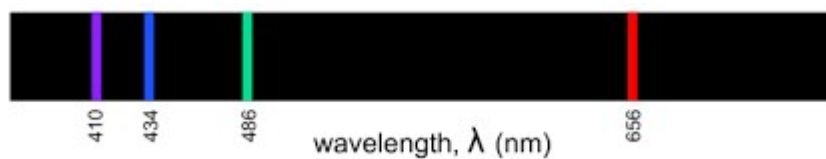
- 14 The standard enthalpy change of formation of two oxides of phosphorus are:



What is the enthalpy change, in kJ mol^{-1} , for the reaction below?



- (A) +4600
(B) +1400
(C) -1400
(D) -4600
- 15 Below is an **emission** spectrum for an element.



What do each of the lines correspond to?

- (A) The energy released when an electron drops from a higher energy level to a lower one.
(B) The energy absorbed when an electron climbs from a lower energy level to a higher one.
(C) The energy required to remove successive electrons from the valence shell.
(D) The energy of all its electrons.

Section 2: Extended Response

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CANDIDATE NUMBER

75 marks

Attempt ALL Questions

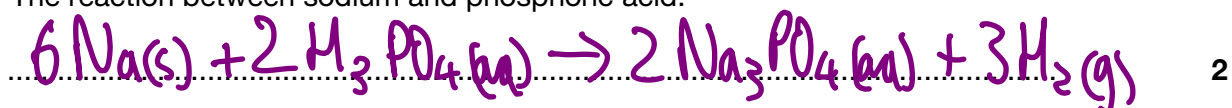
Allow about 1 hour 45 minutes to complete this section.

Question 16 (4 marks)

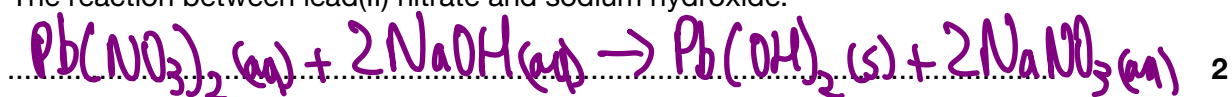
Marks

Write balanced chemical equations for the following reactions.

a) The reaction between sodium and phosphoric acid.



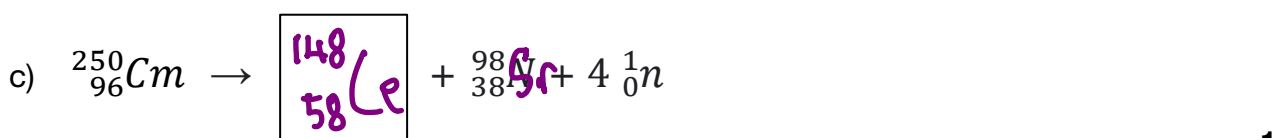
b) The reaction between lead(II) nitrate and sodium hydroxide.



Each: ② All correct
① Some correct components

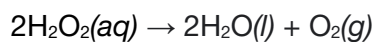
Question 17 (3 marks)

Complete each of the following nuclear equations.

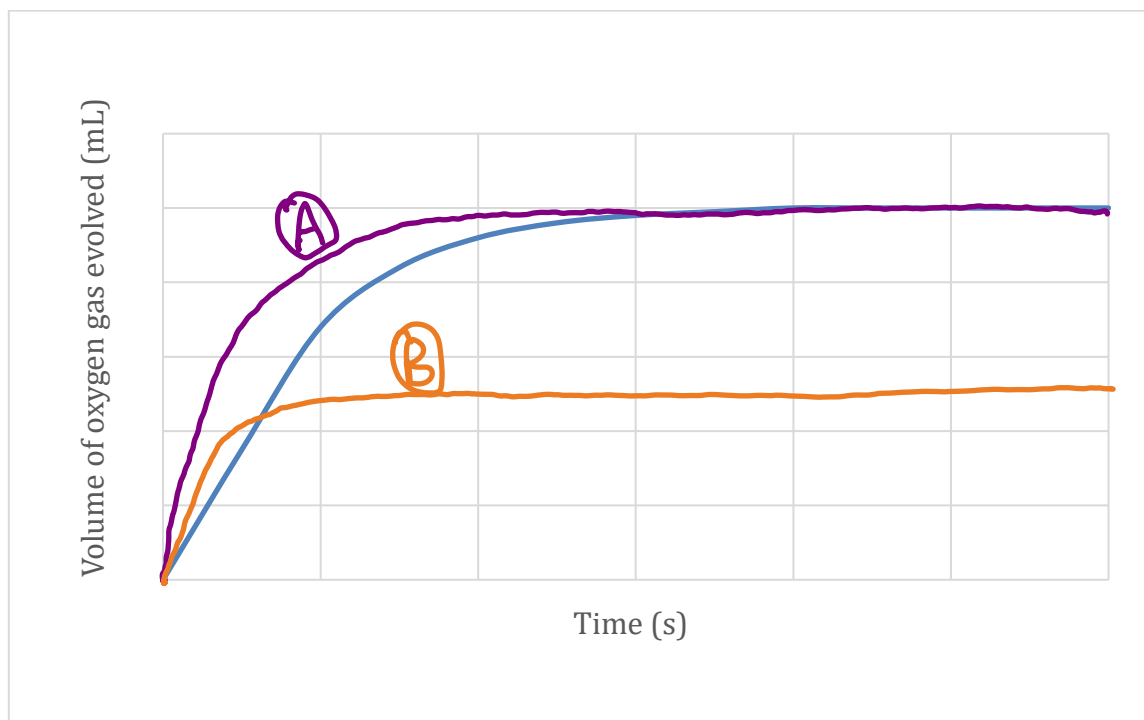


Question 18 (4 marks)**Marks**

Hydrogen peroxide decomposes to produce oxygen gas.



The graph shows the volume of oxygen gas evolved when 50 mL of 1.0 mol L⁻¹ hydrogen peroxide decomposes at 298 K.



On the graph above, sketch how the volume of oxygen gas evolved would change if the experiment was repeated at 298 K using the following:

- a) 25 mL of 2.0 mol L⁻¹ hydrogen peroxide. Label this curve A.

① Faster initial rate

2

① Same final volume

- b) 25 mL of 1.0 mol L⁻¹ hydrogen peroxide in the presence of a manganese dioxide catalyst. Label this curve B.

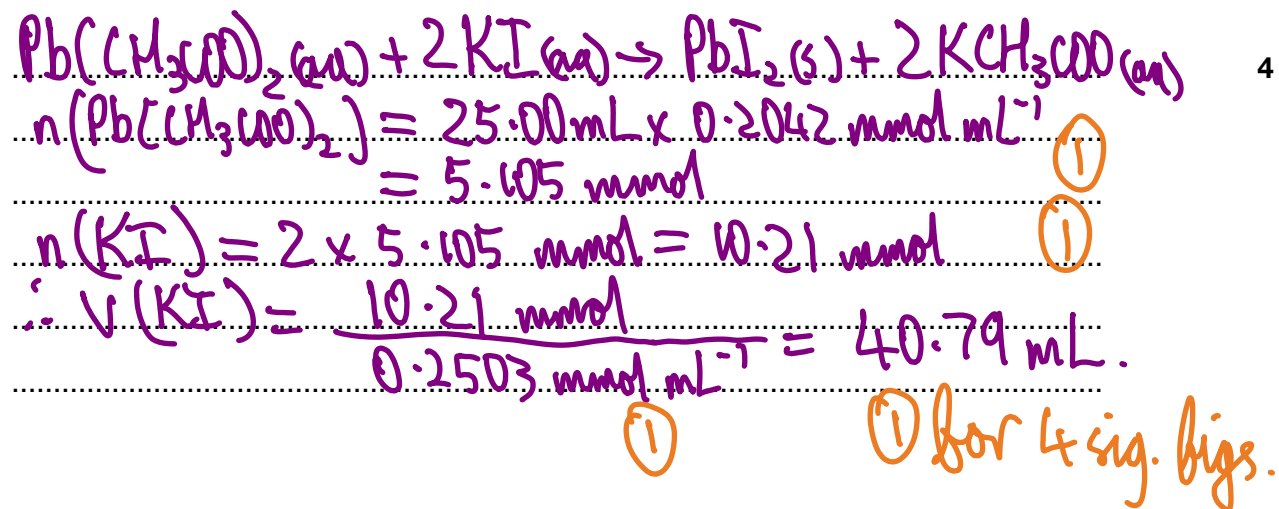
① Faster initial rate

2

① Half final volume

Question 19 (4 marks)**Marks**

Calculate the volume of $0.2503 \text{ mol L}^{-1}$ potassium iodide solution required for complete reaction with 25.00 mL of $0.2042 \text{ mol L}^{-1}$ lead(II) acetate solution.



Question 20 (6 marks)

Compound **X**, a common solvent, contains 62.04% carbon and 27.55% oxygen by mass, with the remainder being hydrogen.

a) Calculate the empirical formula for compound **X**.

$$\%(\text{H}) = 100 - 62.04 - 27.55 = 10.41\%$$

①

.....

3

.....

$$n(\text{C}) = 62.04 / 12.01 = 5.165 \text{ mol}$$

$$n(\text{H}) = 10.41 / 1.008 = 10.33 \text{ mol}$$

$$n(\text{O}) = 27.55 / 16.00 = 1.722 \text{ mol}$$

①

.....

.....

.....

Mole ratio: 3:6:1, so empirical formula is $\text{C}_3\text{H}_6\text{O}$.

①

A 250 mL flask containing 0.6038 g of compound **X** has a pressure of 101.3 kPa and a temperature of 293.0 K.

b) Calculate the molar mass of compound **X**, and hence its molecular formula.

①

3

$$n(\text{X}) = PV / RT = 101.3 \text{ kPa} \times 0.250 \text{ L} / (8.314 \text{ J K}^{-1} \text{ mol}^{-1} \times 293.0 \text{ K}) = 0.01040 \text{ mol}$$

$$\text{MM}(\text{X}) = 0.6038 \text{ g} / 0.01040 \text{ mol} = 58.08 \text{ g mol}^{-1}$$

①

$$\text{MM}(\text{C}_3\text{H}_6\text{O}) = 3 \times 12.01 + 6 \times 1.008 + 16.00 = 58.078 \text{ g mol}^{-1}$$

①

So the molecular formula is also $\text{C}_3\text{H}_6\text{O}$.

.....

Question 21 (4 marks)**Marks**

Dinitrogen monoxide, $\text{N}_2\text{O}(g)$, is used as a rocket fuel. The data in the table below shows how the activation energy, E_A , for the decomposition of dinitrogen monoxide in the presence of different catalysts.



Conditions	E_A (kJ mol^{-1})
no catalyst	245
gold catalyst	121
iron catalyst	116
platinum catalyst	136

a) Use the table to identify the most effective catalyst for this decomposition.

Iron catalyst (1) 1

b) Explain how this catalyst affects the rate of N_2O decomposition in terms of Collision Theory.

Rate of decomposition increases. (1) 3

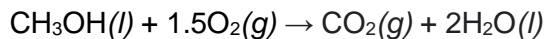
The catalyst provides an alternate reaction pathway with a lower activation energy. (1)

Higher proportions of particles will be able to collide and react successfully with the lower E_a . (1)

.....
.....

Question 22 (8 marks)**Marks**

Two students, John and Marit, were asked to determine the value for the enthalpy of combustion, $\Delta_c H$, of methanol ($\text{CH}_3\text{OH}(l)$).



John used the average bond enthalpies given in the table below.

Bond	Average bond enthalpies (kJ mol^{-1})
C – H	413
C – O	358
O – H	463
O = O	495
C = O	804

- a) Calculate the value for the enthalpy of combustion of methanol obtained by John using the average bond enthalpies given in the table above.

.....
Energy (break bond) = $3(\text{C-H}) + (\text{C-O}) + (\text{O-H}) + 1.5(\text{O=O}) = 2802.5 \text{ kJ/mol}$ (1)

Energy (bond form) = $2(\text{C=O}) + 4(\text{O-H}) = 3460 \text{ kJ/mol}$ (1)

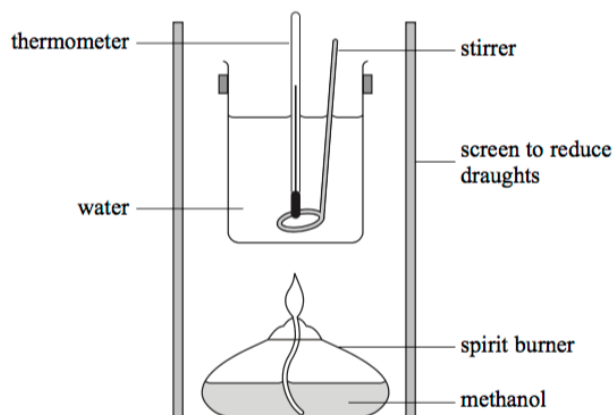
$\Delta H = 2802.5 + (-3460) = -657.5 \text{ kJ/mol}$ (1)

3

Question continues on next page.

Question 22 continued.**Marks**

Marit placed a beaker containing 100 mL of water above a spirit burner containing methanol ($\text{CH}_3\text{OH}(l)$) as shown in the diagram below. She weighed the spirit burner and measured the initial temperature of the water.



Marit lit the spirit burner and waited until the temperature had increased significantly. She weighed the spirit burner again, measured the final temperature of the water and placed all her results into the table below.

Initial mass of spirit burner and methanol	52.550 g
Final mass of spirit burner and methanol	52.268 g
Initial temperature of water	20.1°C
Final temperature of water	30.4°C

b) Calculate the value for the enthalpy of combustion determined by Marit using calorimetry.

$$q = mc(\Delta T) = 0.1 \times 4.18 \times 10^3 \times (30.4 - 20.1) = 4305.4 \text{ J (1)}$$

$$n = (52.550 - 52.268) / 32.042 = 0.0088 \text{ mol (1)}$$

$$\Delta H = -q/n = -4305.4 / 0.0088 = -489.25 \text{ kJ/mol (1)}$$

Question 22 continued.

Marks

The literature value for the standard enthalpy of combustion of methanol is -726 kJ mol^{-1} .

- c) Explain why John obtained a result closer to the literature value for the enthalpy of combustion of methanol than Marit.

Heat loss to the surrounding environment, etc (1)

.....

1

- d) Explain why there is still a difference between John's result and the literature value for the enthalpy of combustion of methanol.

Used **average** bond enthalpy, real values depend on the specific molecule. (1)....

.....

1

Question 23 (5 marks)**Marks**

Orica produces sodium cyanide (NaCN) at its plant in Yarwun, Queensland. It is supplied to the mining industry in tanks containing 24 200 kg of a 30.0%(w/w) aqueous solution.

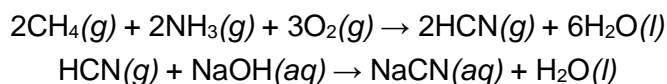
- a) Calculate the mass of sodium cyanide present in each tank.

.....

1

$$m(\text{NaCN}) = 24\,200 \text{ kg} \times 30.0/100 = 7260 \text{ kg (to 3 sig. figs.) (1)}$$

Sodium cyanide is prepared in a two-step process, with the main starting materials being methane, ammonia and sodium hydroxide.



- b) Calculate the mass of ammonia required to produce the mass of sodium cyanide in part (a).

.....

2

$$n(\text{NaCN}) = 7260 \text{ kg} / 49.01 \text{ kg kmol}^{-1} = 148 \text{ kmol (1)}$$

$$n(\text{NH}_3) = n(\text{HCN}) = n(\text{NaCN}) = 148 \text{ kmol}$$

$$m(\text{NH}_3) = 148 \text{ kmol} \times 17.034 \text{ kg kmol}^{-1} = 2520 \text{ kg (to 3 sig figs.) (1)}$$

- c) Calculate the volume (measured at 25°C and 100 kPa) of oxygen gas required to produce the mass of sodium cyanide in part (a).

$$n(\text{O}_2) = 3/2 \times 148 \text{ kmol} = 222 \text{ kmol (1)}$$

$$v(\text{O}_2) = 222 \text{ kmol} \times 24.79 \text{ kL kmol}^{-1} = 5.51 \text{ ML} = 5.51 \times 10^6 \text{ L (1)}$$

Question 24 (6 marks)**Marks**

The fluoride ion and the magnesium ion have the same electron configuration.

a) Write the electron configuration for the two ions using spdf notation.

$1s^2 2s^2 2p^6$ (1)..... **1**

b) State which of the two ions would have a greater ionic radius and explain your choice.

F- would have a greater ionic radius (1) **3**

Isoelectronic configuration or same number of occupied electron shells

F- has less protons / less positive charge in the nucleus / **smaller effective nuclear charge**. Smaller electrostatic attraction from the nucleus to the electrons -> greater ionic radius. (2).....

c) The successive ionisation energies of magnesium are given in the table below.

Ionisation	Ionisation energy (kJ mol ⁻¹)
1	738
2	1451
3	7733

By referencing this data, explain why magnesium forms a Mg²⁺ ion and not a Mg³⁺ ion.

REFERENCE DATA Large jump between IE2 and IE3.(1) **2**

EXPLANATION (1)

EITHER The third electron experiences much less shielding

OR The third electron is held in orbital closer to the nucleus

so more energy required to remove electron.

Question 25 (5 marks)

Marks

Carbon can be found in a variety of forms.

Diamond, an allotrope of carbon, is the hardest naturally occurring substance on Earth.

3 Marks - ALL information given below

2 Marks - missing ONE piece of information below

1 Mark - ANY relevant information

Structure of diamond

Example ANSWER

a) Explain why diamond is such a hard material in terms of structure and bonding.

Missing info
↓

Diamond is a covalent lattice network.

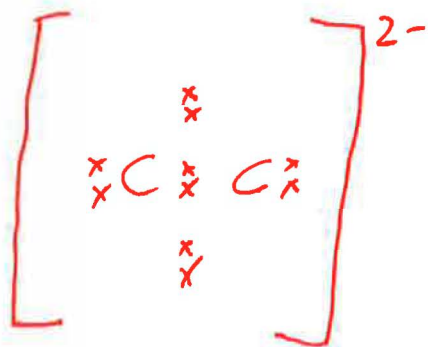
L 3

Each atom is bonded covalently to 4 other atoms (forming a tetrahedral structure)

Hence it would require a great deal of energy to break all these bonds, making diamond hard.

Metal carbides are also hard materials used in computing and machinery.

b) Draw the Lewis dot structure for the carbide ion (C_2^{2-}).



ONE mark lost per mistake

2

Possible mistakes

N - number of electrons

L - location of electrons

Cal or B - charge & loc brackets.

Question 26 (5 marks)

Phosphorus trifluoride, PF_3 , is a colourless and odourless gas.

- a) Deduce whether phosphorus trifluoride will be a polar molecule or not and explain your reasoning.

3 Marks - Comprehensive EXPLANATION including ALL information below

2 Marks - Weak explanation of structure AND bonding
OR detailed explanation of structure OR bonding

1 Mark - ANY relevant information

Missing Information

* P-F bonds are POLAR due to the difference in ELECTRONEGATIVITY of the 2 elements

E 3

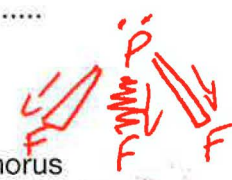
* The shape of PF_3 is TRIGONAL PYRAMIDAL

S

* The combination of the 3 polar bonds and their asymmetrical distribution leads to a polar molecule.

P

Best explanations via a diagram ie



- b) Name the predominant intermolecular force that exists between phosphorus trifluoride molecules and explain how this force arises.

Dipole-Dipole - 1 mark

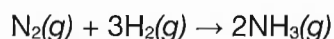
2

The negative end of one molecule is attracted to the positive end of its neighbours 1 mark.

I - confusion of inter & intra molecular IMF - confused or lack of discussion of intermolecular attractions.

Question 27 (9 marks)**Marks**

The production of ammonia is an important reaction in industry.



Some thermodynamic data has been given in the table below.

	$\text{N}_2(\text{g})$	$\text{H}_2(\text{g})$	$\text{NH}_3(\text{g})$
$\Delta_f H^\ominus$ (kJ mol ⁻¹)	0	0	-41
S^\ominus (J K ⁻¹ mol ⁻¹)	193	131	192

- a) Calculate the standard enthalpy change for the reaction.

$$2 \times -41 = -82 \text{ kJ mol}^{-1}$$

1

- b) Calculate the standard entropy change for the reaction.

$$2 \times 192 - (193 + 3 \times 131)$$

$$= -202 \text{ J K}^{-1} \text{ mol}^{-1} \quad \text{Marks lost for incorrect working and/or units.}$$

2

- c) Calculate ΔG for the reaction at 300 K and determine whether the reaction will be spontaneous at this temperature.

$$\Delta G = \Delta H - T\Delta S$$

$$= -82 - 300 \times \frac{-202}{1000}$$

$$= -21.4 \text{ kJ mol}^{-1} \quad \text{1 MARK}$$

2

\therefore Yes the reaction is spontaneous as the ΔG is negative.

Question continues on next page.

Question 27 continued.

Marks

- d) If ammonia was produced as a liquid and not a gas in this reaction, state and explain how the values for ΔH and ΔS would change.

- ✓ ΔH will become more negative 1 MARK
- ✓ $\text{NH}_3(g) \rightarrow \text{NH}_3(l)$ releases energy in the
process of bond formation 1 MARK.
- ✓ ΔS will become more negative 1 MARK.
- ✓ $\text{NH}_3(l)$ is a more organized/less random
state than $\text{NH}_3(g)$ 1 MARK.

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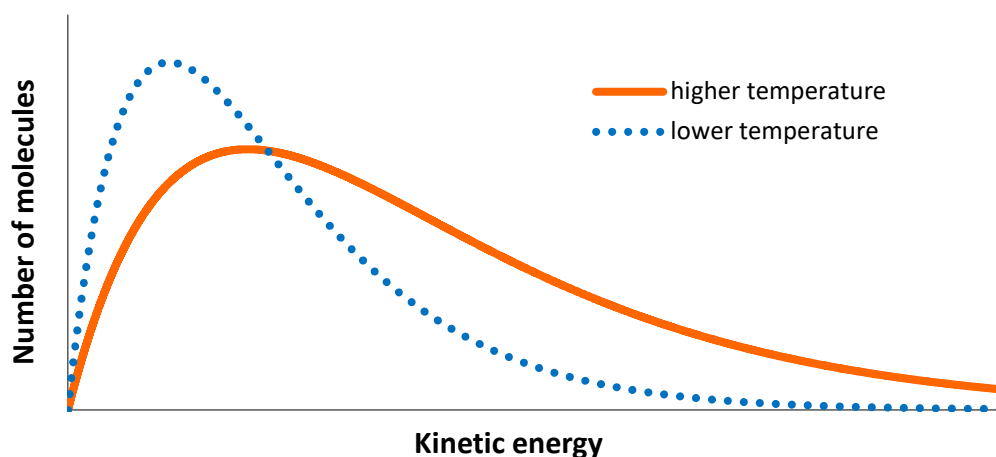
CANDIDATE NUMBER

Marked by JLS

Question 28 (3 marks)

Marks

The Maxwell Boltzmann distribution below shows an energy distribution of a gaseous substance at two different temperatures.



Use the distribution above to explain why increasing the temperature significantly increases the rate of a chemical reaction.

For 3 marks:

- Particles must have $E_K > E_A$ to react/overcome energy barrier when they collide/for successful collision.
- Greater proportion or (more) particles with sufficient energy to react when they collide.
- Greater frequency/higher probability/higher proportion of successful collisions.

For 2 marks:

- Any two of the points above

For 1 mark:

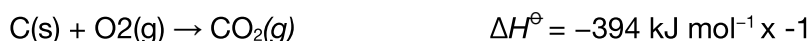
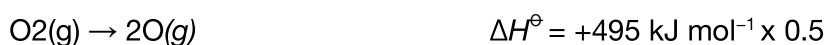
- Any one of the points above
OR Gas particles are moving faster so they collide more often.

Note: Many students gave vague responses

Question 29 (4 marks)**Marks**

Calculate the bond enthalpy of a C≡O bond in kJ mol⁻¹ using the data given below.

Bond enthalpy of O=O bond	$\Delta H^\ominus = +495 \text{ kJ mol}^{-1}$
Enthalpy of formation of CO ₂ (g)	$\Delta H^\ominus = -394 \text{ kJ mol}^{-1}$
C(s) → C(g)	$\Delta H^\ominus = +716 \text{ kJ mol}^{-1}$
2CO ₂ (g) → O ₂ (g) + 2CO(g)	$\Delta H^\ominus = +566 \text{ kJ mol}^{-1}$

Method 1: Using Hess's Law**For 4 marks:**

- Correct answer 1074.5 kJ mol⁻¹
- Full working

For 3 marks:

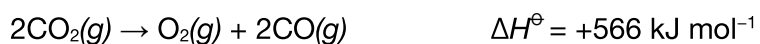
- Correct method with minor error
- Full working

For 2 marks:

- Mostly correct method with working
- 1/2 major errors

For 1 mark:

- Any relevant information

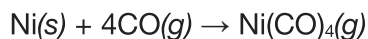
Method 2: Using Hess's law and bond enthalpies

1 mark for writing out equation for formation of CO₂

1 mark for calculating enthalpy of formation of CO.

Question 30 (5 marks)**Marks**

The Mond process is used to purify nickel, by reacting impure nickel with carbon monoxide:



Impure nickel is placed in a 100 L reactor and the reactor pressurised with carbon monoxide gas. The initial pressure in the reactor is 215 kPa and the initial temperature is 295 K. After the mixture in the reactor is heated the reaction takes place. The final pressure in the reactor is 145 kPa and the final temperature is 350 K. Calculate the mass of nickel consumed in this reaction, assuming that the only reaction occurring is shown in the equation above.

Sample answer

$$n(\text{CO, initial}) = (215 \times 100) / (8.314 \times 295) = 8.77 \text{ mol}$$

$$n(\text{gas, final}) = (145 \times 100) / (8.314 \times 350) = 4.98 \text{ mol}$$

$$n(\text{gas consumed}) = 8.77 - 4.98 = 3.78 \text{ mol}$$

For every mole of $\text{Ni(CO)}_4\text{(g)}$ produced, 4 mol of CO(g) are consumed; a net change of -3 mol of gas consumed for every mole of $\text{Ni(CO)}_4\text{(g)}$ produced.

$$n(\text{Ni(CO)}_4 \text{ produced}) = 3.78 \text{ mol} / 3 = 1.26 \text{ mol}$$

$$m(\text{Ni}) = 1.26 \times 58.69 \text{ g mol}^{-1} = 74.0 \text{ g (to 3 s.f.)}$$

For 5 marks

All correct steps and correct answer 74.0 g

For 4 marks

All correct steps, one minor error e.g. rounding error, transcription error

For 3 marks

Any 3 of the 4 correct steps ($n(\text{CO, initial})$ and $n(\text{gas, final})$, $n(\text{gas consumed})$, $n(\text{Ni reacted/Ni(CO)}_4 \text{ produced})$, n into m).

For 2 marks

2 of the 4 correct steps ($n(\text{CO, initial})$ and $n(\text{gas, final})$, $n(\text{gas consumed})$, $n(\text{Ni reacted/Ni(CO)}_4 \text{ produced})$, n into m).

For 1 mark

1 correct step.