This is a Class 1 exam

Lebanon Evangelical School for Boys and Girls

Lebanon Evangelical School
for Boys and Girls Loueizeh - Baabda

Stage Exam 01
06NOV2023

Do NOT write in this box. Your MARK will be placed here.

Subject :	A Level : Chemistry 2	
Class :	12A	
Teacher :	Mrs. Saydeh Nasrallah	
Duration :	2 hours	
Your name :		*Time taken to complete exam*
Your Class :		
Exam Room :		
How many sheets, including cover sheet :		

- Do not open this paper until the teacher in charge instructs you to do so.
- The most important thing to remember in taking an exam is NEVER PANIC.
- If you are caught cheating in this exam, you will be awarded zero for ALL exams that are taken on this day.

SECTION A

Answer ALL the questions in this section.
You should aim to spend no more than 25 minutes on this section.
For each question, select one answer from A to D and put a cross in the box.
If you change your mind, put a line through ☒ the box and then mark your new answer with a cross. ☒

1. The equilibrium position for the dissociation of molten I_2Cl_6 lies to the left.

$$I_2Cl_6 \rightleftharpoons ICl_2^+ + ICl_4^-$$

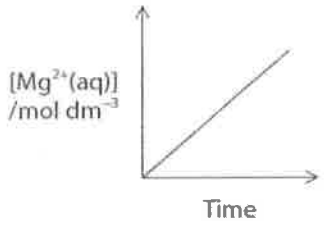
What is the most likely numerical value of K_c for this equilibrium?

☒ **A** 1.0×10^6
☐ **B** 5.0×10^3
☒ **C** 1.0
☒ **D** 5.0×10^{-3}

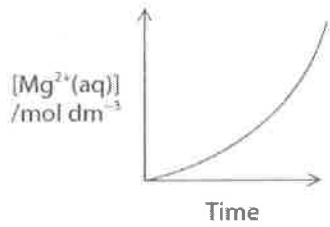
(Total for Question 1 = 1 mark)

2. Which graph shows the change in the concentration of the $Mg^{2+}(aq)$ ions when some solid magnesium hydroxide is shaken with water and left to reach equilibrium?

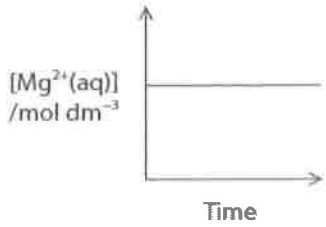
☐ **A**



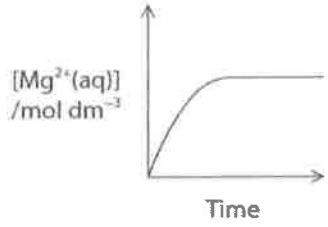
☐ **B**



☐ **C**



☐ **D**



(Total for Question 2 = 1 mark)

3. This question is about enthalpy changes and entropy changes.

(a) Which is the equation for the standard enthalpy change of formation, $\Delta_f H$, of aluminium oxide?

(1)

☒ **A** $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

☒ **B** $4Al(s) + 6O(g) \rightarrow 2Al_2O_3(s)$

☒ **C** $2Al(s) + 1½\ O_2(g) \rightarrow Al_2O_3(s)$

☒ **D** $2Al(s) + 3O(g) \rightarrow Al_2O_3(s)$

(b) Which reaction has a negative value for ΔS_{system}?

(1)

☒ **A** $2Cu(s) + O_2(g) \rightarrow 2CuO(s)$

☒ **B** $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

☒ **C** $MgCO_3(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l) + CO_2(g)$

☐ **D** $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

(c) What is the expression for ΔS_{total}?

(1)

☐ **A** $\Delta S_{surroundings} + \frac{\Delta H}{T}$

☒ **B** $\Delta S_{surroundings} - \frac{\Delta H}{T}$

☒ **C** $\Delta S_{system} + \frac{\Delta H}{T}$

☐ **D** $\Delta S_{system} - \frac{\Delta H}{T}$

(Total for Question 3 = 3 marks)

4. Ammonium carbamate has the formula NH_2COONH_4. When a sample of ammonium carbamate is placed in a sealed tube and heated, it partially decomposes to the compounds used to synthesise it. The equation for this reversible reaction is

$$NH_2COONH_4(s) \rightleftharpoons 2NH_3(g) + CO_2(g)$$

Which is the expression for the equilibrium constant, K_c , for this reaction?

All concentration terms are at equilibrium.

☒ **A** $\frac{[NH_3][CO_2]}{[NH_2COONH_4]}$

☒ **B** $\frac{[2NH_3][CO_2]}{[NH_2COONH_4]}$

☒ **C** $[NH_3]^2[CO_2]$

☐ **D** $\frac{[NH_3]^2[CO_2]}{[NH_2COONH_4]}$

(Total for Question 4 = 1 mark)

5. The reaction shown occurs at 360 °C and 1 atm.

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \Delta H = -41.2\,kJ\,mol^{-1}$$

What is the type of equilibrium and how is K_c affected by an **increase** in temperature?

	Type of equilibrium	Effect of increasing temperature on K_c
☐ **A**	heterogeneous	decreases
☐ **B**	homogeneous	decreases
☒ **C**	heterogeneous	increases
☐ **D**	homogeneous	increases

(Total for Question 5 = 1 mark)

6. What are the units of K_p for the equilibrium shown?

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

☐ **A** atm^{-1}
☐ **B** atm
☒ **C** atm^{-2}
☐ **D** atm^{2}

(Total for Question 6 = 1 mark)

7. Which is **not** a conjugate acid-base pair?

☒ **A** NH_3, NH_2^-
☒ **B** NH_4^+, NH_3
☒ **C** H_2CO_3, CO_3^{2-}
☒ **D** H_2CO_3, HCO_3^-

(Total for Question 7 = 1 mark)

8. What is the pH of the solution when 2.15 g of barium hydroxide is dissolved in $200\,cm^3$ of deionised water?

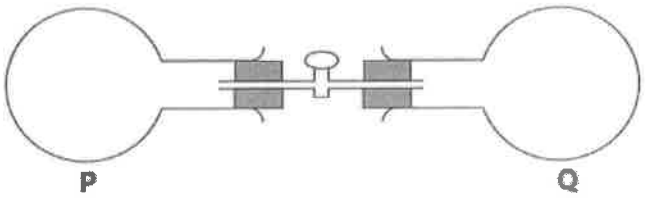
[molar mass of barium hydroxide = $171.3\,g\,mol^{-1}$

$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$]

☒ **A** 10.1
☒ **B** 12.1
☒ **C** 12.8
☒ **D** 13.1

(Total for Question 8 = 1 mark)

9. Two flasks, **P** and **Q**, are connected by a tube fitted with a tap.



Flask **P** contains argon gas and flask **Q** is in vacuum.

Assume argon behaves as an ideal gas and therefore has no intermolecular forces between its atoms.

How do the entropy and energy of the system change when the tap is opened and the argon fills both flasks?

	Entropy of the system	Energy of the system
☒ **A**	increases	decreases
☒ **B**	decreases	decreases
☒ **C**	increases	unchanged
☒ **D**	decreases	unchanged

(Total for Question 9 = 1 mark)

10. When hydrogen and oxygen are mixed in a flask, there is no reaction.
When a platinum gauze is added to the flask, the mixture explodes.
It can be deduced that, in the absence of a platinum gauze, the mixture of hydrogen and oxygen is

- ☐ **A** kinetically stable and thermodynamically stable
- ☐ **B** kinetically stable and thermodynamically unstable
- ☒ **C** kinetically unstable and thermodynamically stable
- ☐ **D** kinetically unstable and thermodynamically unstable

(Total for Question 10 = 1 mark)

11. The decomposition of hydrogen peroxide is catalysed by iodide ions.

$$2H_2O_2(aq) \xrightarrow{I^-} 2H_2O(l) + O_2(g)$$

The mechanism for this reaction is shown.

Step 1:	$H_2O_2(aq) + I^-(aq) \rightleftharpoons IO^-(aq) + H_2O(l)$	fast
Step 2:	$H_2O_2(aq) + IO^-(aq) \rightarrow I^-(aq) + H_2O(l) + O_2(g)$	slow

What is the rate equation for this reaction?

- ☐ **A** rate = $k[H_2O_2]^2[I^-]$
- ☐ **B** rate = $k[H_2O_2][I^-]$
- ☐ **C** rate = $k[H_2O_2]^2[I^-][IO^-]$
- ☐ **D** rate = $k[H_2O_2][IO^-]$

(Total for Question 11 = 1 mark)

12. Propanone reacts with iodine in both acidic and alkaline conditions.

(a) The products of the reactions under the stated conditions include

(1)

	Acidic conditions	Alkaline conditions
☒ A	CH_3I	CH_3COO^-
☒ B	CH_3COCI_3	CH_3COO^-
☒ C	CH_3COCH_2I	CH_3I
☒ D	CH_3COCH_2I	CHI_3

(b) The rate equation for the reaction between propanone and iodine in acidic conditions is

$$\text{rate} = k[H^+][CH_3COCH_3]$$

The reaction was carried out at two different pH values, all other conditions remaining unchanged.
In the first reaction pH = 2.0
In the second reaction the rate was found to be $\frac{1}{3}$ of the original value.
What was the pH of the second reaction, to 1 decimal place?

(1)

☐ A 0.7
☐ B 1.5
☐ C 2.5
☐ D 2.7

(Total for Question 12 = 2 marks)

13. The reaction shown is at equilibrium. The forward reaction is endothermic.

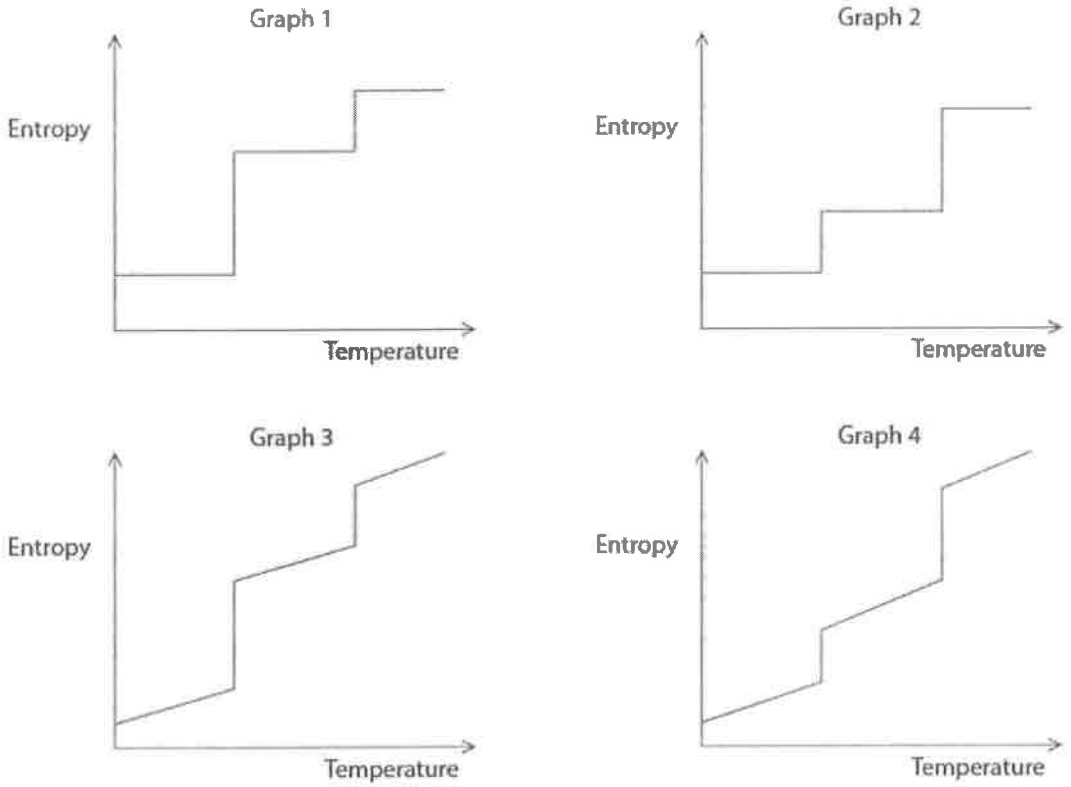
$$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$$

At 680 °C and 1 atm, 52.6 % of the molecules in the gas mixture are carbon monoxide.
What is the partial pressure of carbon dioxide, in atmospheres?

☐ A 0.237
☐ B 0.263
☐ C 0.474
☐ D 0.526

(Total for Question 13 = 1 mark)

14. Which graph shows the entropy of a substance as it changes state from solid to liquid to gas?



☐ A Graph 1
☐ B Graph 2
☐ C Graph 3
☐ D Graph 4

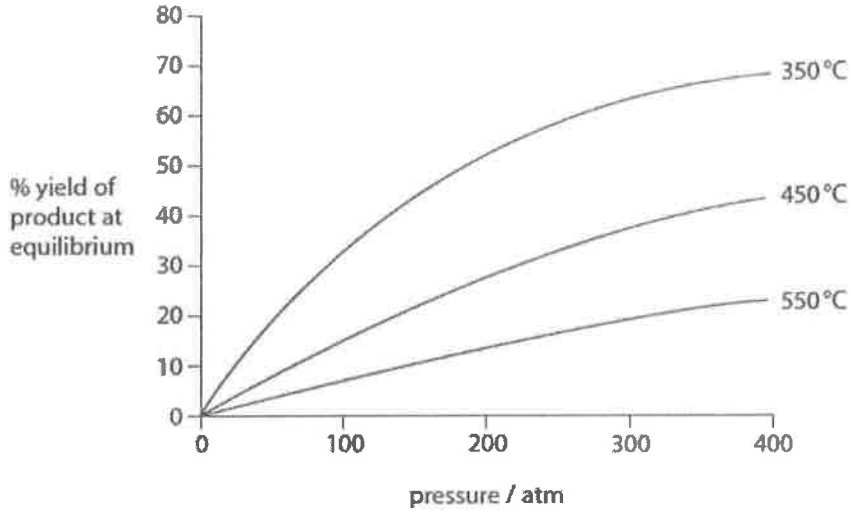
(Total for Question 14 = 1 mark)

15. An ionic compound is found to have some degree of covalent bonding.
What will be the cause of the covalency and how will the lattice energy obtained from a Born–Haber cycle differ from the theoretical value obtained from electrostatic theory?

	Cause of covalency	Born–Haber lattice energy compared with theoretical value
☐ A	cation polarised by anion	Born–Haber more exothermic
☐ B	anion polarised by cation	Born–Haber less exothermic
☐ C	cation polarised by anion	Born–Haber less exothermic
☐ D	anion polarised by cation	Born–Haber more exothermic

(Total for Question 15 = 1 mark)

16. The graph shows the percentage yield of a product in a gaseous equilibrium under different conditions.



The forward reaction in the equilibrium is

☒ **A** exothermic with the number of moles of gas decreasing.
☒ **B** exothermic with the number of moles of gas increasing.
☒ **C** endothermic with the number of moles of gas decreasing.
☒ **D** endothermic with the number of moles of gas increasing.

(Total for Question 16 = 1 mark)

17. Which is the correct expression for $R\ln K$?

☐ **A** $R\ln K = \Delta S_{system} - \Delta H/T$
☐ **B** $R\ln K = \Delta S_{system} + \Delta H/T$
☐ **C** $R\ln K = \Delta S_{system} - T\Delta H$
☐ **D** $R\ln K = \Delta S_{system} + T\Delta H$

(Total for Question 17 = 1 mark)

18. The standard molar entropy, S, of a substance is zero for all

- ☐ **A** elements under standard conditions.
- ☐ **B** monatomic gases under standard conditions.
- ☐ **C** perfect crystals at absolute zero (0K).
- ☐ **D** substances in a system at equilibrium.

(Total for Question 18 = 1 mark)

19. When dilute aqueous solutions of potassium manganate(VII), ethanedioic acid and sulfuric acid are mixed, the following reaction occurs:

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

The rate of reaction is slow at first, accelerates rapidly and then gradually slows down.
The best explanation for these observations is that the

- ☐ **A** reaction is exothermic, so after a small amount of reaction the temperature rises sharply.
- ☐ **B** reaction is acid catalysed and the formation of carbon dioxide results in an increased concentration of hydrogen ions.
- ☐ **C** reaction is catalysed by the manganese(II) ions which are formed in the reaction.
- ☐ **D** high concentration of hydrogen ions from the sulfuric acid inhibits the dissociation of the ethanedioic acid.

(Total for Question 19 = 1 mark)

20. Energy is given out when one mole of gaseous strontium ions is hydrated.

$$Sr^{2+}(g) + aq \rightarrow Sr^{2+}(aq)$$

This reaction is less exothermic than the corresponding reaction for magnesium ions, $Mg^{2+}(g)$, because

- ☐ **A** the sum of the first two ionization energies of magnesium is more than that of strontium.
- ☐ **B** the lattice energies of magnesium compounds are more exothermic than the lattice energies of corresponding strontium compounds.
- ☐ **C** the solubility of magnesium hydroxide is less than the solubility of strontium hydroxide.
- ☐ **D** the ionic radius of Mg^{2+} is less than the ionic radius of Sr^{2+}.

(Total for Question 20 = 1 mark)

TOTAL FOR SECTION A = 23 MARKS

SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

21. This question is about lattice energies.

(a) The table shows the theoretical and experimental lattice energy values of two compounds.

Compound	Theoretical lattice energy / $kJmol^{-1}$	Experimental lattice energy / $kJmol^{-1}$
Magnesium iodide	-1944	-2327
Barium iodide	-1831	-1877

(i) State what can be deduced by the close similarity of the lattice energy values for barium iodide.

(1)

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(ii) Explain why there is a significant difference in the lattice energy values for magnesium iodide.

(4)

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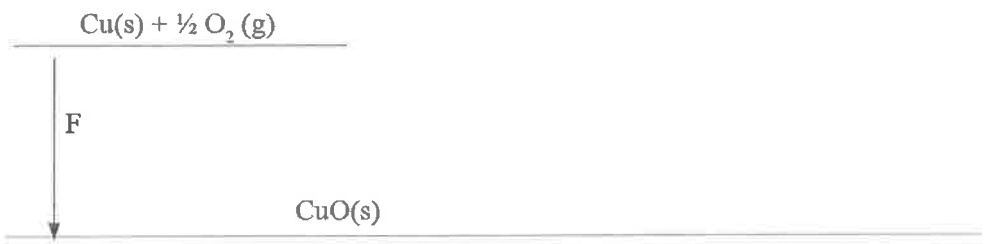
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(b) Data for the Born-Haber cycle for copper(II) oxide are given in the table.

Label	Energy change	Value / $kJmol^{-1}$
A	standard enthalpy change of atomisation of copper	+338
B	standard enthalpy change of atomisation of oxygen	+249
C	sum of first and second ionisation energies of copper	+2704
D	first electron affinity of oxygen	-141
E	second electron affinity of oxygen	+798
F	standard enthalpy change of formation of copper(II) oxide	-157

(i) Complete the diagram of the Born-Haber cycle for copper(II) oxide.
Include labels of enthalpy changes with arrows indicating the direction of change, and the respective species with state symbols.

(4)



(ii) Calculate the lattice energy of copper(II) oxide.

(2)

(c) A different energy cycle can be used to calculate lattice energy.
Using the values given in the table below, complete the cycle and calculate the lattice energy of calcium bromide.
Include labels of enthalpy changes with arrows indicating the direction of change, and the respective species with state symbols.

(5)

Enthalpy change	Value / $kJmol^{-1}$
enthalpy change of solution of $CaBr_2$	-73
enthalpy change of hydration of Ca^{2+}	-1577
enthalpy change of hydration of Br^-	-336

$Ca^{2+}(g) + 2Br^-(g) \longrightarrow CaBr_2(s)$

(Total for Question 21 = 16 marks)

***22.** A student wrote:

> Whether or not a reaction occurs depends only on the thermodynamic feasibility calculated using
>
> $$\Delta S_T = \Delta S_{system} + \Delta S_{surroundings}$$

Discuss this statement.
Include reference to:

- changes in the values and signs of the terms in the equation for both endothermic and exothermic reactions
- circumstances where a reaction that is predicted to be thermodynamically feasible may not occur in practice.

(6)

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(Total for Question 22 = 6 marks)

23. This is a question about catalysis.

(a) The reaction between iodide ions and peroxodisulfate ions is catalysed by iron(II) ions.

$$2I^- + S_2O_8^{2-} \xrightarrow{Fe^{2+}} I_2 + 2SO_4^{2-}$$

(i) Give a reason why the reaction between iodide ions and peroxodisulfate ions has a high activation energy and is therefore very slow without a catalyst.

(1)

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(ii) Explain, with the aid of two equations, how the iron(II) ions catalyse this reaction. State symbols are not required.

(3)

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(b) The oxidation of sulfate(IV) ions to sulfate(VI) ions is catalysed by cobalt(II) ions in acidic solution. The role of cobalt(II) ions is similar to that of iron(II) ions in (a).

$$SO_3^{2-} + \tfrac{1}{2}O_2 \xrightarrow{Co^{2+}} SO_4^{2-}$$

Complete the two ionic equations to show how cobalt(II) ions catalyse the reaction in **acidic** solution. State symbols are not required.

(2)

..... Co^{2+} + ... O_2 + ... H^+ → ..... + H_2O

..... Co^{3+} + ... + H_2O → $2Co^{2+}$ + SO_4^{2-} + ...

(c) A catalytic converter decreases the emissions of gases, such as carbon monoxide and nitrogen monoxide, from an internal combustion engine.

(i) Describe the stages in a catalytic converter that result in this decrease.
No equations are required.

(3)

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(ii) The trend in the strength of gaseous adsorption by three transition elements is

tungsten > platinum > silver

Silver is not suitable as a replacement for platinum in a catalytic converter because the adsorption of gases is too weak to allow significant chemical reaction.
Give a possible reason why tungsten would also **not** be a suitable replacement for platinum in a catalytic converter.

(1)

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(Total for Question 23 = 10 marks)

24. The equation for the ionisation of water is

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

(a) Write the expression for the ionic product of water K_w .

(1)

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(b) The value of K_w at 310K is $2.40 \times 10^{-14} mol^2 dm^{-6}$
Calculate the pH of water at 310K. Give your answer to **two** decimal places.

(2)

(c) Predict, with a reason, whether water is acidic, alkaline or neutral at 310K.

(2)

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(d) Predict, with a reason, the sign of the enthalpy change for the ionisation of water.
Given: $K_w = 10^{-14} mol^2 dm^{-6}$ at 298K.

(2)

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(Total for Question 24 = 7 marks)

25. Ammonia is manufactured by the Haber Process.

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

(a) Write an expression of k_p for the above equilibrium.

(1)

(b) The pressure used in the Haber Process is 200 atm.
Using the expression of k_p , explain the effect, if any, of increasing the pressure on the equilibrium yield of ammonia.

(3)

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(c) The equilibrium constants for K_p and K_c are related by the equation

$$K_p = \frac{K_c}{(RT)^{\Delta n}}$$

where Δn is the number of moles of reactants minus the number of moles of products.
Calculate the value of K_c at 500K when the value of $K_p = 3.55 \times 10^{-2} atm^{-2}$.
Include the units for K_c .
[Use the value of $R = 0.0821 dm^3 atm K^{-1} mol^{-1}$]

(4)

(d) A mixture of 1.0 mol of nitrogen and 3.0 mol of hydrogen is left to reach equilibrium at 700K.

Calculate the total pressure, in atmospheres, needed to produce a yield of 0.30 mol of ammonia at 700K.

Give your answer to an appropriate number of significant figures.

You must show your working.

Given $K_p = 7.76 \times 10^{-5} atm^{-2}$ at 700K.

(6)

(e) The value of the equilibrium constant, K_p , varies with temperature.

The equation relating the values of the equilibrium constant at two temperatures is

$$\ln[\frac{K_2}{K_1}]=\frac{\Delta H}{R}[\frac{1}{T_1}-\frac{1}{T_2}]$$

The equilibrium constant, K_1 , for the formation of ammonia is $6.76\times10^5 atm^{-2}$ when the temperature $T_1=298\,K$.

The enthalpy change $\Delta H=-92400\,J\,mol^{-1}$.

Calculate the value of the equilibrium constant, K_2 for this reaction at temperature $T_2=310\,K$.

[Use the value of $R=8.31\,J\,mol^{-1}K^{-1}$]

(4)

(Total for Question 25 = 18 marks)

26. Cracking reactions are used to obtain more useful compounds from the alkanes found in crude oil. An equation for the cracking of butane is shown.

$$C_4H_{10}(g) \rightarrow C_2H_6(g) + C_2H_4(g)$$

Thermodynamic data for the compounds in this reaction are given in the table.

	$C_4H_{10}(g)$	$C_2H_6(g)$	$C_2H_4(g)$
Standard molar entropy $S^\ominus$ / $JK^{-1}mol^{-1}$	310.1	229.5	219.5
Standard molar enthalpy change of formation $\Delta_f H^\ominus$ / $kJ\,mol^{-1}$	−126.5	−84.7	+52.2

(a) Calculate the entropy change in the system, ΔS_{system}, for the cracking of butane.
Include a sign and units with your answer.

(2)

(b) Calculate the enthalpy change of reaction, $\Delta_r H$, for the cracking of butane.
Include a sign and units with your answer.

(2)

(c) Calculate the entropy change in the surroundings, $\Delta S_{surroundings}$, at 298 K for the cracking of butane, using your answer to (a)(ii).
Include a sign and units with your answer.

(2)

(d) Calculate the total entropy change, ΔS_{total}, at 298 K for the cracking of butane, using your answers to (a)(i) and (a)(iii).
Include a sign and units with your answer.

(1)

(e) Calculate the temperature at which the cracking reaction becomes feasible.

(2)

(Total for Question 26 = 9 marks)
TOTAL FOR SECTION B = 66 MARKS

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

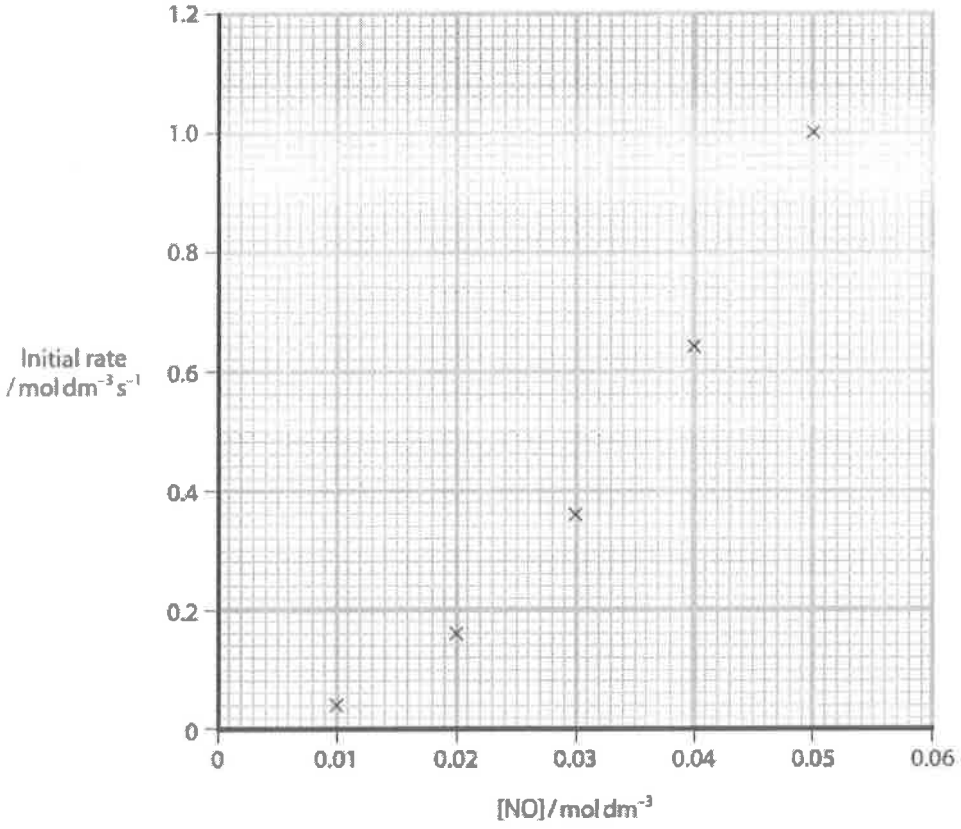
27. This question is about the reaction between nitrogen monoxide and oxygen.

$$NO(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons NO_2(g)$$

(a) The results of a series of kinetics experiments are shown.

Experiment	Initial [NO] /mol dm^{-3}	Initial [O_2] /mol dm^{-3}	Initial rate /mol dm^{-3} s^{-1}
1	0.010	0.050	0.040
2	0.020	0.050	0.160
3	0.030	0.050	0.360
4	0.040	0.050	0.641
5	0.050	0.050	1.001
6	0.020	0.025	0.080

The data for experiments 1–5 were plotted on a graph.



(i) Draw a best-fit curve on the graph.

(1)

(ii) State how the graph shows that the reaction is not first order with respect to nitrogen monoxide.

(1)

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(iii) Deduce the orders of reaction with respect to NO and O_2, using the data from experiments 1–6.

(2)

Order with respect to NO = ...

Order with respect to O_2 = ...

(iv) Write the rate equation for the reaction, using your answer to (a)(iii).

(1)

.....

(v) Calculate the rate constant for this reaction using the data from experiment 1 and your rate equation. Include units in your answer.

(2)

(b) The equilibrium constant, K_p , for the reaction at 298K is $1.55 \times 10^5 atm^{-½}$.
State what this value of the equilibrium constant indicates about the position of the equilibrium. Justify your answer.

(2)

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(c) One of the uses of nitrogen dioxide is the manufacturing of nitric acid.

A commercial nitric acid solution, $HNO_3(aq)$, has a concentration of $15.9\,mol\,dm^{-3}$.
A $1.50\,cm^3$ sample was made up to $1000\,cm^3$ by adding deionised water.

Calculate the pH of this diluted solution.

(2)

(Total for Question 27 = 11 marks)

TOTAL FOR SECTION C = 11 MARKS
TOTAL FOR PAPER = 100 MARKS

The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8) (18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La* lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac* actinium 89	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	[147] Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
232 Th thorium 90	[231] Pa protactinium 91	238 U uranium 92	[237] Np neptunium 93	[242] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[245] Bk berkelium 97	[251] Cf californium 98	[254] Es einsteinium 99	[253] Fm fermium 100	[256] Md mendelevium 101	[254] No nobelium 102	[257] Lr lawrencium 103

* Lanthanide series

* Actinide series

SECTION A

Answer ALL the questions in this section.
You should aim to spend no more than 25 minutes on this section.
For each question, select one answer from A to D and put a cross in the box.
If you change your mind, put a line through ☒ the box and then mark your new answer with a cross. ☒

1. The equilibrium position for the dissociation of molten I_2Cl_6 lies to the left.

$$I_2Cl_6 \rightleftharpoons ICl_2^+ + ICl_4^-$$

What is the most likely numerical value of K_c for this equilibrium?

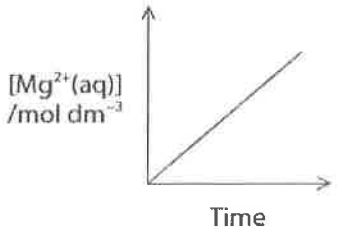
☐ **A** 1.0×10^6
☐ **B** 5.0×10^3
☐ **C** 1.0
☒ **D** 5.0×10^{-3}

(1) ✓

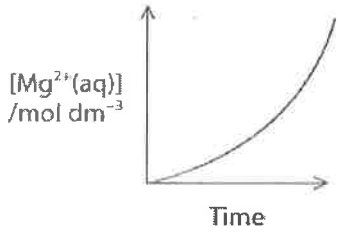
(Total for Question 1 = 1 mark)

2. Which graph shows the change in the concentration of the $Mg^{2+}(aq)$ ions when some solid magnesium hydroxide is shaken with water and left to reach equilibrium?

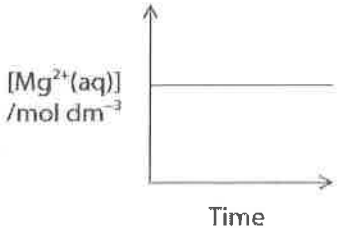
☐ **A**



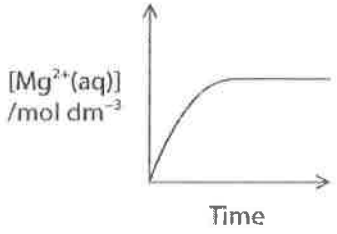
☐ **B**



☐ **C**



☒ **D**



✓ (1)

(Total for Question 2 = 1 mark)

3. This question is about enthalpy changes and entropy changes.

(a) Which is the equation for the standard enthalpy change of formation, $\Delta_f H$, of aluminium oxide?

(1)

☐ **A** $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

☐ **B** $4Al(s) + 6O(g) \rightarrow 2Al_2O_3(s)$

☒ **C** $2Al(s) + 1½\ O_2(g) \rightarrow Al_2O_3(s)$

☐ **D** $2Al(s) + 3O(g) \rightarrow Al_2O_3(s)$

(b) Which reaction has a negative value for ΔS_{system}?

(1)

☒ **A** $2Cu(s) + O_2(g) \rightarrow 2CuO(s)$

☐ **B** $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

☐ **C** $MgCO_3(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2O(l) + CO_2(g)$

☐ **D** $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

(c) What is the expression for ΔS_{total}?

(1)

☐ **A** $\Delta S_{surroundings} + \frac{\Delta H}{T}$

☐ **B** $\Delta S_{surroundings} - \frac{\Delta H}{T}$

☐ **C** $\Delta S_{system} + \frac{\Delta H}{T}$

☒ **D** $\Delta S_{system} - \frac{\Delta H}{T}$

(Total for Question 3 = 3 marks)

4. Ammonium carbamate has the formula NH_2COONH_4. When a sample of ammonium carbamate is placed in a sealed tube and heated, it partially decomposes to the compounds used to synthesise it. The equation for this reversible reaction is

$$NH_2COONH_4(s) \rightleftharpoons 2NH_3(g) + CO_2(g)$$

Which is the expression for the equilibrium constant, K_c, for this reaction?

All concentration terms are at equilibrium.

☐ **A** $\frac{[NH_3][CO_2]}{[NH_2COONH_4]}$

☐ **B** $\frac{[2NH_3][CO_2]}{[NH_2COONH_4]}$

☒ **C** $[NH_3]^2[CO_2]$

☐ **D** $\frac{[NH_3]^2[CO_2]}{[NH_2COONH_4]}$

(Total for Question 4 = 1 mark)

5. The reaction shown occurs at 360 °C and 1 atm.

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad \Delta H = -41.2\,kJ\,mol^{-1}$$

What is the type of equilibrium and how is K_c affected by an **increase** in temperature?

		Type of equilibrium	Effect of increasing temperature on K_c
☐	**A**	heterogeneous	decreases
☒	**B**	homogeneous	decreases
☐	**C**	heterogeneous	increases
☐	**D**	homogeneous	increases

(Total for Question 5 = 1 mark)

6. What are the units of K_p for the equilibrium shown?

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

☐ **A** atm^{-1}
☐ **B** atm
☒ **C** atm^{-2}
☐ **D** atm^2

(Total for Question 6 = 1 mark)

7. Which is **not** a conjugate acid-base pair?

☐ **A** NH_3, NH_2^-
☐ **B** NH_4^+, NH_3
☒ **C** H_2CO_3, CO_3^{2-}
☐ **D** H_2CO_3, HCO_3^-

(Total for Question 7 = 1 mark)

8. What is the pH of the solution when 2.15 g of barium hydroxide is dissolved in $200\,cm^3$ of deionised water?

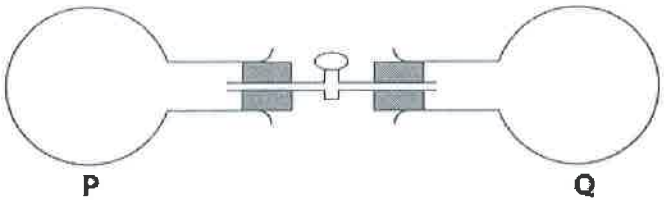
[molar mass of barium hydroxide = $171.3\,g\,mol^{-1}$

$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$]

- ☐ A 10.1
- ☐ B 12.1
- ☐ C 12.8
- ☒ D 13.1

(Total for Question 8 = 1 mark)

9. Two flasks, **P** and **Q**, are connected by a tube fitted with a tap.



Flask **P** contains argon gas and flask **Q** is in vacuum.

Assume argon behaves as an ideal gas and therefore has no intermolecular forces between its atoms.

How do the entropy and energy of the system change when the tap is opened and the argon fills both flasks?

	Entropy of the system	Energy of the system
☒ **A**	increases	decreases
☒ **B**	decreases	decreases
☒ **C**	increases	unchanged
☒ **D**	decreases	unchanged

(Total for Question 9 = 1 mark)

10. When hydrogen and oxygen are mixed in a flask, there is no reaction.
When a platinum gauze is added to the flask, the mixture explodes.
It can be deduced that, in the absence of a platinum gauze, the mixture of hydrogen and oxygen is

(1) ✓
- ☐ **A** kinetically stable and thermodynamically stable
- ☒ **B** kinetically stable and thermodynamically unstable
- ☐ **C** kinetically unstable and thermodynamically stable
- ☐ **D** kinetically unstable and thermodynamically unstable

(Total for Question 10 = 1 mark)

11. The decomposition of hydrogen peroxide is catalysed by iodide ions.

$$2H_2O_2(aq) \xrightarrow{I^-} 2H_2O(l) + O_2(g)$$

The mechanism for this reaction is shown.

Step 1:	$H_2O_2(aq) + I^-(aq) \rightleftharpoons IO^-(aq) + H_2O(l)$	fast
Step 2:	$H_2O_2(aq) + IO^-(aq) \rightarrow I^-(aq) + H_2O(l) + O_2(g)$	slow

What is the rate equation for this reaction?

(1) ✓
- ☒ **A** rate = $k[H_2O_2]^2[I^-]$
- ☐ **B** rate = $k[H_2O_2][I^-]$
- ☐ **C** rate = $k[H_2O_2]^2[I^-][IO^-]$
- ☐ **D** rate = $k[H_2O_2][IO^-]$

(Total for Question 11 = 1 mark)

12. Propanone reacts with iodine in both acidic and alkaline conditions.

(a) The products of the reactions under the stated conditions include

(1)

		Acidic conditions	Alkaline conditions
☐	**A**	CH_3I	CH_3COO^-
☐	**B**	CH_3COCI_3	CH_3COO^-
☐	**C**	CH_3COCH_2I	CH_3I
☒	**D**	CH_3COCH_2I	CHI_3

(1) ✓

(b) The rate equation for the reaction between propanone and iodine in acidic conditions is

$$\text{rate} = k[H^+][CH_3COCH_3]$$

The reaction was carried out at two different pH values, all other conditions remaining unchanged.
In the first reaction pH = 2.0
In the second reaction the rate was found to be $\frac{1}{3}$ of the original value.
What was the pH of the second reaction, to 1 decimal place?

(1)

☐ **A** 0.7
☐ **B** 1.5
☒ **C** 2.5
☐ **D** 2.7

(1) ✓

(Total for Question 12 = 2 marks)

13. The reaction shown is at equilibrium. The forward reaction is endothermic.

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

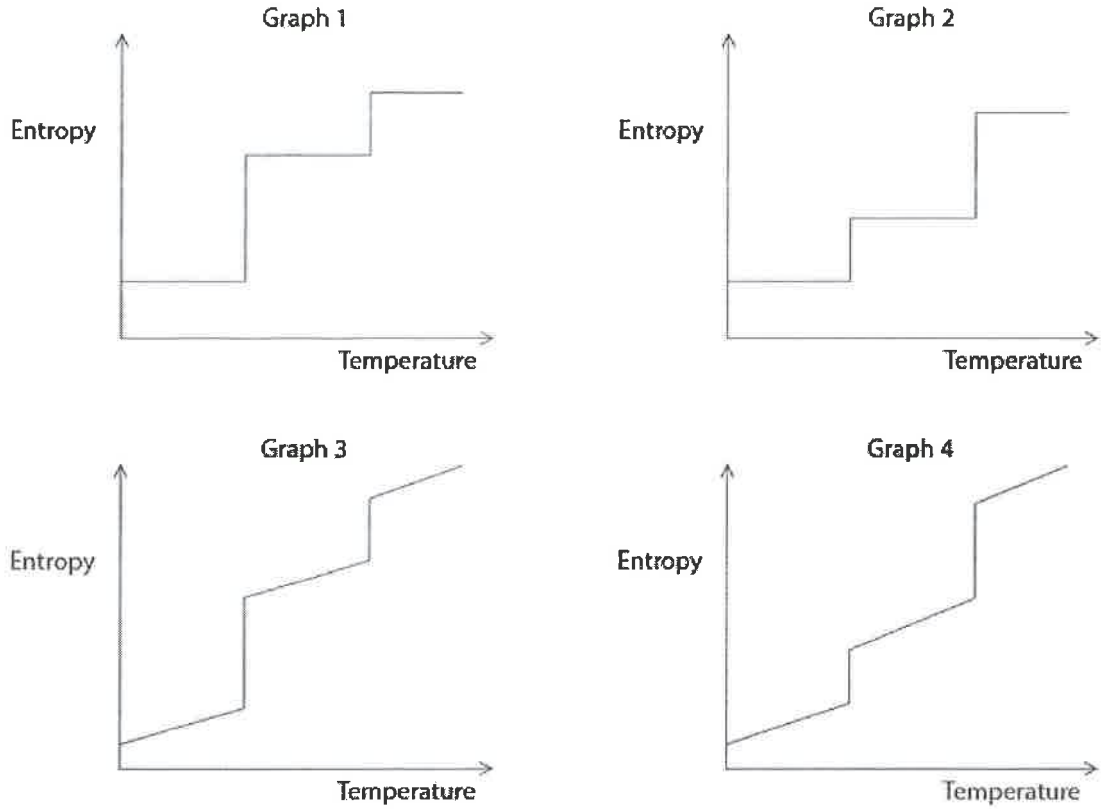
At 680 °C and 1 atm, 52.6 % of the molecules in the gas mixture are carbon monoxide.
What is the partial pressure of carbon dioxide, in atmospheres?

☐ **A** 0.237
☐ **B** 0.263
☒ **C** 0.474
☐ **D** 0.526

(1) ✓

(Total for Question 13 = 1 mark)

14. Which graph shows the entropy of a substance as it changes state from solid to liquid to gas?



- ☒ **A** Graph 1
- ☒ **B** Graph 2
- ☒ **C** Graph 3
- ☒ **D** Graph 4

(1) ✓

(Total for Question 14 = 1 mark)

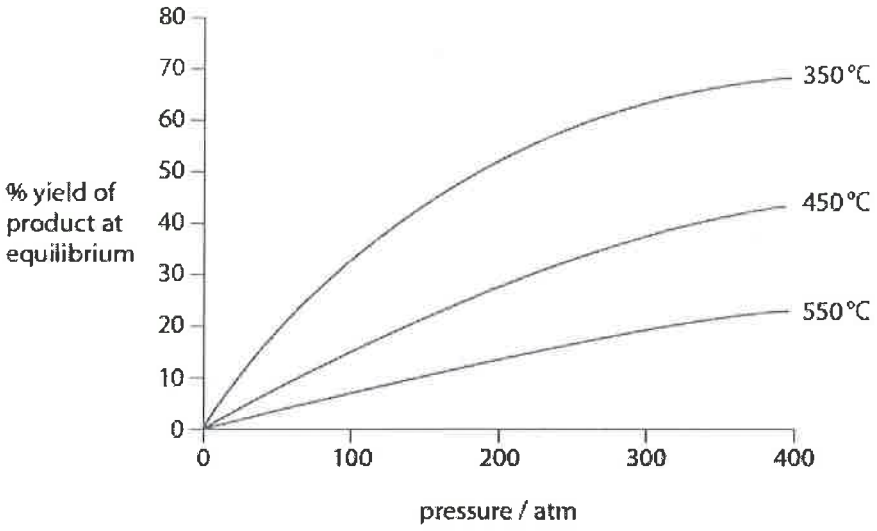
15. An ionic compound is found to have some degree of covalent bonding.
What will be the cause of the covalency and how will the lattice energy obtained from a Born–Haber cycle differ from the theoretical value obtained from electrostatic theory?

	Cause of covalency	Born–Haber lattice energy compared with theoretical value
☐ **A**	cation polarised by anion	Born–Haber more exothermic
☐ **B**	anion polarised by cation	Born–Haber less exothermic
☐ **C**	cation polarised by anion	Born–Haber less exothermic
☒ **D**	anion polarised by cation	Born–Haber more exothermic

(1) ✓

(Total for Question 15 = 1 mark)

16. The graph shows the percentage yield of a product in a gaseous equilibrium under different conditions.



The forward reaction in the equilibrium is

(1)

☒ **A** exothermic with the number of moles of gas decreasing.
☐ **B** exothermic with the number of moles of gas increasing.
☐ **C** endothermic with the number of moles of gas decreasing.
☐ **D** endothermic with the number of moles of gas increasing.

(Total for Question 16 = 1 mark)

17. Which is the correct expression for $R\ln K$?

(1)

☒ **A** $R\ln K = \Delta S_{system} - \Delta H/T$
☐ **B** $R\ln K = \Delta S_{system} + \Delta H/T$
☐ **C** $R\ln K = \Delta S_{system} - T\Delta H$
☐ **D** $R\ln K = \Delta S_{system} + T\Delta H$

(Total for Question 17 = 1 mark)

18. The standard molar entropy, S, of a substance is zero for all

- ☐ **A** elements under standard conditions.
- ☐ **B** monatomic gases under standard conditions.
- ☒ **C** perfect crystals at absolute zero (0K).
- ☐ **D** substances in a system at equilibrium.

(Total for Question 18 = 1 mark)

19. When dilute aqueous solutions of potassium manganate(VII), ethanedioic acid and sulfuric acid are mixed, the following reaction occurs:

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

The rate of reaction is slow at first, accelerates rapidly and then gradually slows down.
The best explanation for these observations is that the

- ☐ **A** reaction is exothermic, so after a small amount of reaction the temperature rises sharply.
- ☐ **B** reaction is acid catalysed and the formation of carbon dioxide results in an increased concentration of hydrogen ions.
- ☒ **C** reaction is catalysed by the manganese(II) ions which are formed in the reaction.
- ☐ **D** high concentration of hydrogen ions from the sulfuric acid inhibits the dissociation of the ethanedioic acid.

(Total for Question 19 = 1 mark)

20. Energy is given out when one mole of gaseous strontium ions is hydrated.

$$Sr^{2+}(g) + aq \rightarrow Sr^{2+}(aq)$$

This reaction is less exothermic than the corresponding reaction for magnesium ions, $Mg^{2+}(g)$, because

- ☐ **A** the sum of the first two ionization energies of magnesium is more than that of strontium.
- ☐ **B** the lattice energies of magnesium compounds are more exothermic than the lattice energies of corresponding strontium compounds.
- ☐ **C** the solubility of magnesium hydroxide is less than the solubility of strontium hydroxide.
- ☒ **D** the ionic radius of Mg^{2+} is less than the ionic radius of Sr^{2+}.

(Total for Question 20 = 1 mark)

TOTAL FOR SECTION A = 23 MARKS

SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

21. This question is about lattice energies.

(a) The table shows the theoretical and experimental lattice energy values of two compounds.

Compound	Theoretical lattice energy / $kJmol^{-1}$	Experimental lattice energy / $kJmol^{-1}$
Magnesium iodide	-1944	-2327
Barium iodide	-1831	-1877

(i) State what can be deduced by the close similarity of the lattice energy values for barium iodide.

(1)

It's mostly ionic ✓ (1)

(ii) Explain why there is a significant difference in the lattice energy values for magnesium iodide.

(4)

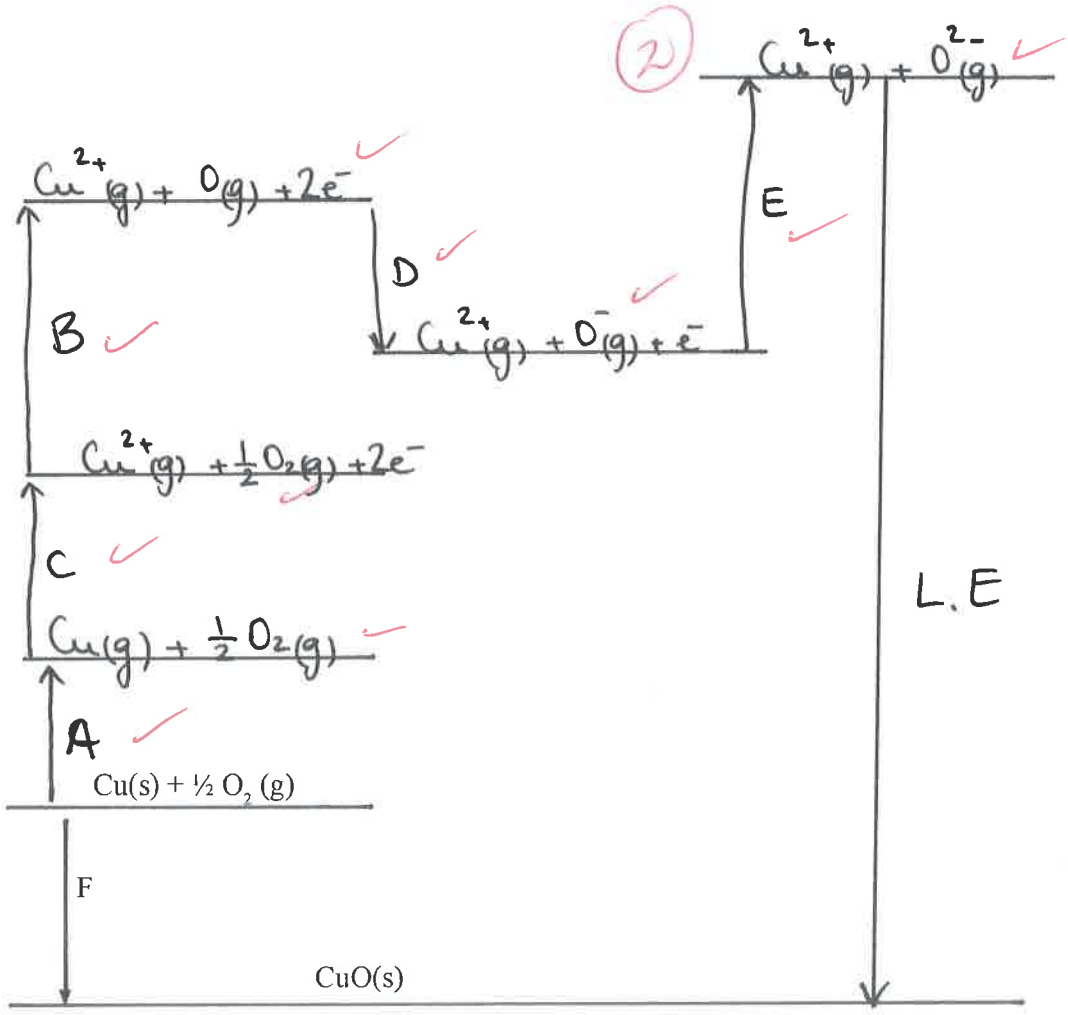
- The structure of MgI_2 consists of cations with high charge density (Mg^{2+}) and large anions (I^-). ✓ (1)
- Mg^{2+} ions have high polarising effect which will cause a great distortion of I^- e^- cloud, leading to a high covalent character. ✓ (1)
- Then $d_{(Mg^{2+}, I^-)}$ (actual) is less than the theoretical d assumed in the ionic model. ✓ (1)
- Therefore the experimental L.E would be more exothermic than the theoretical. ✓ (1)

(b) Data for the Born-Haber cycle for copper(II) oxide are given in the table.

Label	Energy change	Value / $kJmol^{-1}$
A	standard enthalpy change of atomisation of copper	+338
B	standard enthalpy change of atomisation of oxygen	+249
C	sum of first and second ionisation energies of copper	+2704
D	first electron affinity of oxygen	-141
E	second electron affinity of oxygen	+798
F	standard enthalpy change of formation of copper(II) oxide	-157

(i) Complete the diagram of the Born-Haber cycle for copper(II) oxide.
Include labels of enthalpy changes with arrows indicating the direction of change, and the respective species with state symbols.

(4)



(ii) Calculate the lattice energy of copper(II) oxide.

(2)

$F = A + C + B + D + E + L.E$

$\Rightarrow L.E = F - (A + C + B + D + E)$

$= -157 - (338 + 249 + 2704 + (-141) + 798) = -4105 \text{ kg.mol}^{-1}$

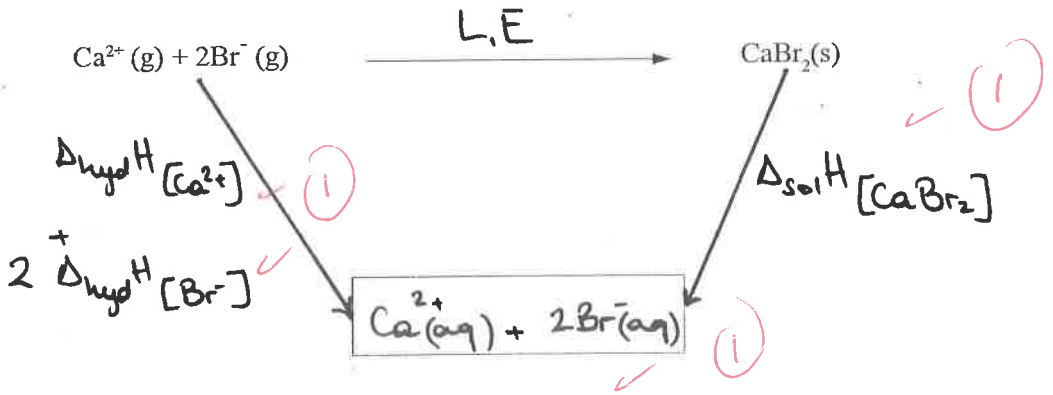
(c) A different energy cycle can be used to calculate lattice energy.

Using the values given in the table below, complete the cycle and calculate the lattice energy of calcium bromide.

Include labels of enthalpy changes with arrows indicating the direction of change, and the respective species with state symbols.

(5)

Enthalpy change	Value / $kJmol^{-1}$
enthalpy change of solution of $CaBr_2$	-73
enthalpy change of hydration of Ca^{2+}	-1577
enthalpy change of hydration of Br^-	-336



$L.E = \Delta_{hyd}H_{[Ca^{2+}]} + 2.\Delta_{hyd}H_{[Br^-]} - \Delta_{sol}H_{[CaBr_2]}$

$= -1577 + 2(-336) + 73$

$= -2176 \text{ kg.mol}^{-1}$

(Total for Question 21 = 16 marks)

*22. A student wrote:

> Whether or not a reaction occurs depends only on the thermodynamic feasibility calculated using
>
> $$\Delta S_T = \Delta S_{system} + \Delta S_{surroundings}$$

Discuss this statement.
Include reference to:

- changes in the values and signs of the terms in the equation for both endothermic and exothermic reactions
- circumstances where a reaction that is predicted to be thermodynamically feasible may not occur in practice.

$\Delta S_{surr} = -\frac{\Delta H}{T}$ and $\Delta S_{system} = \Sigma S^{\circ}_{p} - \Sigma S^{\circ}_{r}$ (6) ✓ (1)

For endothermic reactions, $\Delta S_{surroundings}$ is always negative. Then, there should be a great increase in entropy of the system to overcome the negative value of $\Delta S_{surroundings}$ for the reaction to become thermodynamically feasible. Otherwise, $|\Delta S_{system}| < |\Delta S_{surroundings}|$ which makes ΔS_T negative, hence the reaction becomes thermodynamically not feasible. ✓ (1)

For exothermic reactions, $\Delta S_{surroundings}$ is always positive. Then a small increase in entropy of the system would result in a feasible reaction. ✓

Yet, if there is a decrease in entropy

of the system, the reaction remains thermodynamically feasible as long as (1)

$|\Delta S_{system}| < |\Delta S_{surroundings}|$

For any thermodynamically feasible reaction, whether it's exothermic or endothermic, should the reactants mixture be kinetically inert / stable, then the reaction would not occur without a trigger giving / (1) providing the particles enough energy to overcome the high activation energy of the reaction.

2 pts for the quality of written english

(Total for Question 22 = 6 marks)

23. This is a question about catalysis.

(a) The reaction between iodide ions and peroxodisulfate ions is catalysed by iron(II) ions.

$$2I^- + S_2O_8^{2-} \xrightarrow{Fe^{2+}} I_2 + 2SO_4^{2-}$$

(i) Give a reason why the reaction between iodide ions and peroxodisulfate ions has a high activation energy and is therefore very slow without a catalyst.

(1)

The reactants are both negatively charged, ✓
hence great E is needed to overcome repulsion. (1)

(ii) Explain, with the aid of two equations, how the iron(II) ions catalyse this reaction. State symbols are not required.

(3)

$2Fe^{2+} + S_2O_8^{2-} \longrightarrow 2SO_4^{2-} + 2Fe^{3+}$ ✓(1)

$2Fe^{3+} + 2I^- \longrightarrow I_2 + 2Fe^{2+}$ ✓(1)

Fe^{2+} are oxidised to Fe^{3+} in the 1st step and
then reduced back to Fe^{2+} by I^- in 2nd step. ✓(1)

(b) The oxidation of sulfate(IV) ions to sulfate(VI) ions is catalysed by cobalt(II) ions in acidic solution. The role of cobalt(II) ions is similar to that of iron(II) ions in (a).

$$SO_3^{2-} + \tfrac{1}{2}O_2 \xrightarrow{Co^{2+}} SO_4^{2-}$$

Complete the two ionic equations to show how cobalt(II) ions catalyse the reaction in **acidic** solution. State symbols are not required.

(2)

$2\ Co^{2+} + \frac{1}{2}\ O_2 + 2\ H^+ \rightarrow 2Co^{3+} + H_2O$ ✓(1)

$2\ Co^{3+} + SO_3^{2-} + H_2O \rightarrow 2Co^{2+} + SO_4^{2-} + 2H^+$ ✓(1)

(c) A catalytic converter decreases the emissions of gases, such as carbon monoxide and nitrogen monoxide, from an internal combustion engine.

(i) Describe the stages in a catalytic converter that result in this decrease.
No equations are required.

(3)

(1) Adsorption ✓; where the particles are attracted to the surface of the catalyst ✓ (1)

(2) Reaction ✓; old bonds are broken and new bonds are formed ✓ (1)

(3) Desorption ✓; where the new compounds formed leave the surface of the catalyst ✓ (1)

(ii) The trend in the strength of gaseous adsorption by three transition elements is

tungsten > platinum > silver

Silver is not suitable as a replacement for platinum in a catalytic converter because the adsorption of gases is too weak to allow significant chemical reaction.
Give a possible reason why tungsten would also **not** be a suitable replacement for platinum in a catalytic converter.

(1)

The adsorption is too strong to a point that few particles react in the 2nd step. ✓ (1)

(Total for Question 23 = 10 marks)

24. The equation for the ionisation of water is

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

(a) Write the expression for the ionic product of water K_w .

(1)

$k_w = [H^+][OH^-]$ ✓(1)

(b) The value of K_w at 310K is $2.40 \times 10^{-14} mol^2 dm^{-6}$
Calculate the pH of water at 310K. Give your answer to **two** decimal places.

(2)

$[H^+] = [OH^-] \Rightarrow [H^+] = \sqrt{2.4 \times 10^{-14}} = 1.55 \times 10^{-7}$ mol.dm^{-3} (1)

$pH = -\log(1.55 \times 10^{-7}) = 6.81$ ✓(1)

(c) Predict, with a reason, whether water is acidic, alkaline or neutral at 310K.

(2)

In water, and according to the ionisation equilibrium, $[H^+] = [OH^-]$ at any temperature ✓(1)
Then H_2O is neutral at 310 k ✓(1)

(d) Predict, with a reason, the sign of the enthalpy change for the ionisation of water.
Given: $K_w = 10^{-14} mol^2 dm^{-6}$ at 298K.

(2)

At 310 k, $[H^+] > [H^+]_{298K}$ ✓

$\Rightarrow$ the ionisation increased with the increase in temperature ✓(1)

$\Rightarrow$ the forward reaction is endothermic (1)

(Total for Question 24 = 7 marks)

25. Ammonia is manufactured by the Haber Process.

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

(a) Write an expression of k_p for the above equilibrium.

(1)

$k_p = \dfrac{P_{NH_3}^2}{P_{N_2} \times P_{H_2}^3}$ at equilibrium. ✓(1)

(b) The pressure used in the Haber Process is 200 atm.
Using the expression of k_p, explain the effect, if any, of increasing the pressure on the equilibrium yield of ammonia.

(3)

If $P' > 200$ atm $\Rightarrow Q_p = \dfrac{P'^2_{NH_3}}{P'_{N_2} \times P'^3_{H_2}} = \dfrac{a^2 . P^2_{NH_3}}{a . P_{N_2} . a^3 . P^3_{H_2}}$

$(P' = a \times P)$

$\Rightarrow Q_p = \dfrac{k_p}{a^2}$ ✓(1)

$\Rightarrow Q_p$ should increase ✓(1)

$\Rightarrow$ yield of ammonia increases. ✓(1)

(c) The equilibrium constants for K_p and K_c are related by the equation

$$K_p = \frac{K_c}{(RT)^{\Delta n}}$$

where Δn is the number of moles of reactants minus the number of moles of products.
Calculate the value of K_c at 500K when the value of $K_p = 3.55 \times 10^{-2} atm^{-2}$.
Include the units for K_c.
[Use the value of $R = 0.0821 dm^3 atm K^{-1} mol^{-1}$]

(4)

$K_c = k_p (RT)^{\Delta n}$

$= 3.55 \times 10^{-2} \times (0.0821 \times 500)^2$ ✓(2)

$= 59.8 \quad mol^{-2} . dm^6$

✓(1) ✓(1)

(d) A mixture of 1.0 mol of nitrogen and 3.0 mol of hydrogen is left to reach equilibrium at 700K.

Calculate the total pressure, in atmospheres, needed to produce a yield of 0.30 mol of ammonia at 700K.

Give your answer to an appropriate number of significant figures.

You must show your working.

Given $K_p = 7.76 \times 10^{-5} atm^{-2}$ at 700K.

(6)

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

	N_2	$3H_2$	$2NH_3$
$t=0$:	1	3	—
reacted / formed :	$-\frac{1}{2}\times 0.30$ ✓	$-\frac{3}{2}\times 0.30$ ✓	$+0.30$
t_{eqm} :	0.85 ✓ (1)	2.55 ✓ (1)	0.30

@ eqm : $n_T = 0.85 + 2.55 + 0.30 = 3.70$ mol ✓ (1)

$$k_p = \frac{\left(\frac{0.30}{3.70} \times P\right)^2}{\left(\frac{0.85}{3.70} \times P\right)\left(\frac{2.55}{3.70} \times P\right)^3} \quad \checkmark \ (1)$$

$$\Rightarrow 7.76 \times 10^{-5} = \frac{(0.3)^2 (3.7)^2}{(0.85)(2.55)^3 \cdot P^2}$$

$$\Rightarrow P = \sqrt{\frac{(0.3)^2 (3.7)^2}{(0.85)(2.55)^3 \times 7.76 \times 10^{-5}}} \quad \checkmark \ (1)$$

$$\Rightarrow P = 33.6 \text{ atm} \quad \checkmark \ (1)$$

(e) The value of the equilibrium constant, K_p , varies with temperature.

The equation relating the values of the equilibrium constant at two temperatures is

$$\ln[\frac{K_2}{K_1}]=\frac{\Delta H}{R}[\frac{1}{T_1}-\frac{1}{T_2}]$$

The equilibrium constant, K_1 , for the formation of ammonia is $6.76\times10^5 atm^{-2}$ when the temperature $T_1=298\,K$.

The enthalpy change $\Delta H=-92400\,J\,mol^{-1}$.

Calculate the value of the equilibrium constant, K_2 for this reaction at temperature $T_2=310\,K$.

[Use the value of $R=8.31\,J\,mol^{-1}K^{-1}$]

(4)

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{-92400}{8.31}\left(\frac{1}{298}-\frac{1}{310}\right) \checkmark (1)$$

$$\Rightarrow \ln\left(\frac{K_2}{K_1}\right) = -1.44 \checkmark (1)$$

$$\Rightarrow \frac{K_2}{K_1} = e^{-1.44} \checkmark (1)$$

$$\Rightarrow K_2 = 6.76\times10^5 \times e^{-1.44} = 1.6\times10^5 \checkmark (1)$$

(Total for Question 25 = 18 marks)

26. Cracking reactions are used to obtain more useful compounds from the alkanes found in crude oil. An equation for the cracking of butane is shown.

$$C_4H_{10}(g) \rightarrow C_2H_6(g) + C_2H_4(g)$$

Thermodynamic data for the compounds in this reaction are given in the table.

	$C_4H_{10}(g)$	$C_2H_6(g)$	$C_2H_4(g)$
Standard molar entropy $S^{\ominus}$ / $JK^{-1}mol^{-1}$	310.1	229.5	219.5
Standard molar enthalpy change of formation $\Delta_f H^{\ominus}$ / $kJ\,mol^{-1}$	−126.5	−84.7	+52.2

(a) Calculate the entropy change in the system, ΔS_{system}, for the cracking of butane.
Include a sign and units with your answer.

(2)

$\Delta S_{sys} = 219.5 + 229.5 - 310.1$ ✓

$= +138.9 \text{ J.mol}^{-1}.\text{K}^{-1}$ ✓ (2)

(b) Calculate the enthalpy change of reaction, $\Delta_r H$, for the cracking of butane.
Include a sign and units with your answer.

(2)

$\Delta_r H = 52.2 - 84.7 + 126.5$ ✓

$= +94 \text{ kJ.mol}^{-1}$ ✓ (2)

(c) Calculate the entropy change in the surroundings, $\Delta S_{surroundings}$, at 298 K for the cracking of butane, using your answer to (a)(ii).
Include a sign and units with your answer.

(2)

$\Delta S_{surr} = -\frac{\Delta H}{T} = -\frac{94 \times 10^3}{298} = -315.4 \text{ J.mol}^{-1}.\text{K}^{-1}$ ✓ ✓ (2)

(d) Calculate the total entropy change, ΔS_{total}, at 298 K for the cracking of butane, using your answers to (a)(i) and (a)(iii).
Include a sign and units with your answer.

(1)

$\Delta S_T = 138.9 - 315.4 = -176.5$ J.mol^{-1}.K^{-1} ✓ (1)

(e) Calculate the temperature at which the cracking reaction becomes feasible.

(2)

$\Delta S_T > 0 \Rightarrow 138.9 - \frac{94 \times 10^3}{T} > 0$ ✓ (1)

$\Rightarrow \frac{94 \times 10^3}{T} < 138.9$

$\Rightarrow T > \frac{94 \times 10^3}{138.9}$

$\Rightarrow T > 677$ K. ✓ (1)

(Total for Question 26 = 9 marks)
TOTAL FOR SECTION B = 66 MARKS

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

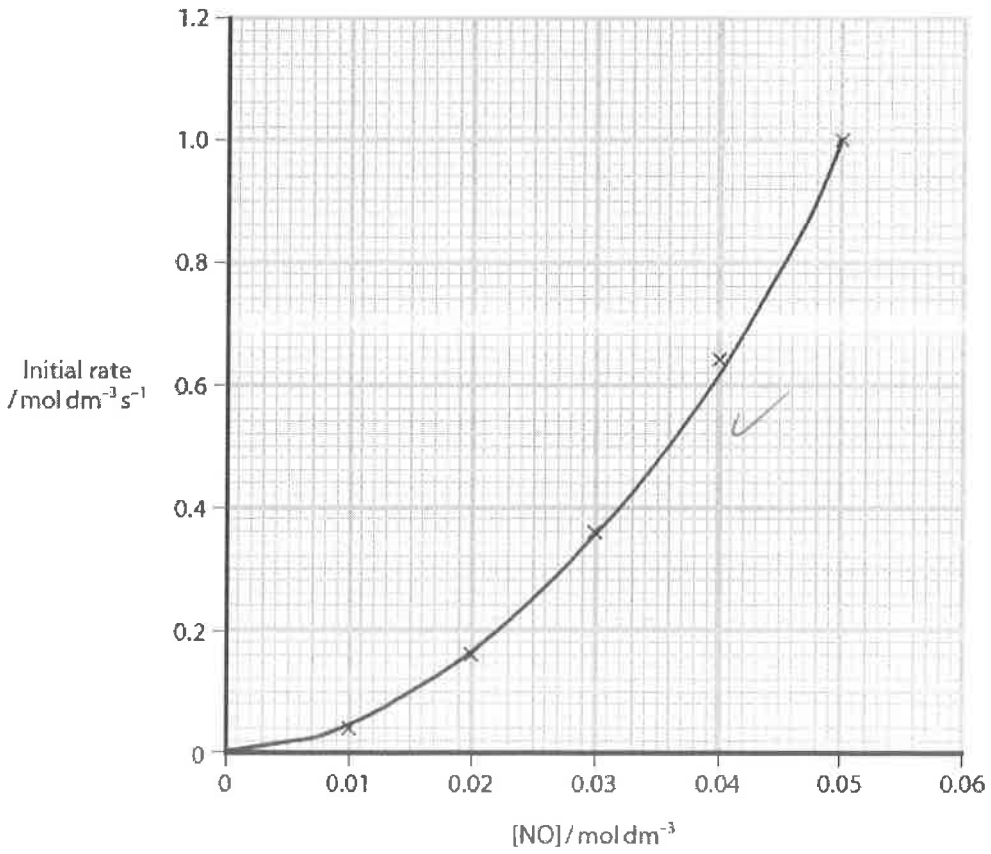
27. This question is about the reaction between nitrogen monoxide and oxygen.

$$NO(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons NO_2(g)$$

(a) The results of a series of kinetics experiments are shown.

Experiment	Initial [NO] / mol dm^{-3}	Initial [O_2] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.010	0.050	0.040
2	0.020	0.050	0.160
3	0.030	0.050	0.360
4	0.040	0.050	0.641
5	0.050	0.050	1.001
6	0.020	0.025	0.080

The data for experiments 1–5 were plotted on a graph.



(i) Draw a best-fit curve on the graph.

(1)

(ii) State how the graph shows that the reaction is not first order with respect to nitrogen monoxide.

(1)

It's a parabolic graph ✓ (1)

(iii) Deduce the orders of reaction with respect to NO and O_2, using the data from experiments 1–6.

(2)

Order with respect to NO = 2 ✓ (1)

Order with respect to O_2 = 1 ✓ (1)

(iv) Write the rate equation for the reaction, using your answer to (a)(iii).

(1)

$r = k[NO]^2[O_2]$ ✓ (1)

(v) Calculate the rate constant for this reaction using the data from experiment 1 and your rate equation. Include units in your answer.

(2)

$$k = \frac{0.04}{(0.01)^2(0.05)} = \frac{4 \times 10^{-2}}{5 \times 10^{-2} \times 10^{-4}} = 8 \times 10^3 \ mol^{-2}.dm^6.s^{-1}$$

✓ (1) ✓ (1)

(b) The equilibrium constant, K_p, for the reaction at 298K is $1.55 \times 10^6 atm^{-½}$.
State what this value of the equilibrium constant indicates about the position of the equilibrium. Justify your answer.

(2)

k_p is of the magnitude of 10^6, and

$\Delta S_T = R \ln k$ ✓

Then at equilibrium, the amount of products is 10^6 the amount of reactants ✓ (1)

Therefore, the equilibrium lies more to the products' side ✓ (1)

(c) One of the uses of nitrogen dioxide is the manufacturing of nitric acid.

A commercial nitric acid solution, $HNO_3(aq)$, has a concentration of $15.9\,mol\,dm^{-3}$.
A $1.50\,cm^3$ sample was made up to $1000\,cm^3$ by adding deionised water.

Calculate the pH of this diluted solution.

(2)

$n_{(H^+)} = 1.5 \times 10^{-3} \times 15.9 = 2.385 \times 10^{-2}$ mol ✓

$[H^+]$ upon dilution $= \dfrac{2.385 \times 10^{-2}}{1000 \times 10^{-3}} = 2.385 \times 10^{-2}$ mol.dm^{-3} (1)

$pH = -\log(2.385 \times 10^{-2}) = 1.62$ ✓ (1)

(Total for Question 27 = 11 marks)

TOTAL FOR SECTION C = 11 MARKS
TOTAL FOR PAPER = 100 MARKS

The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8) (18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La* lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac* actinium 89	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	[147] Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
232 Th thorium 90	[231] Pa protactinium 91	238 U uranium 92	[237] Np neptunium 93	[242] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[245] Bk berkelium 97	[251] Cf californium 98	[254] Es einsteinium 99	[253] Fm fermium 100	[256] Md mendelevium 101	[254] No nobelium 102	[257] Lr lawrencium 103

* Lanthanide series

* Actinide series