This is a Class 1 exam

Lebanon Evangelical School for Boys and Girls

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Loueizeh - Baabda

# Lebanon Evangelical School

for Boys and Girls Loueizeh - Baabda

# SE01 Exam

## 09NOV2026

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 |
| You are to answer the questions to this exam on : this exam paper | |

| | | |
|---|---|---|
| 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.** Which pair of enthalpy changes will **always** share the same sign (i.e. both are always exothermic or both are always endothermic)?

- ☐ **A** enthalpy change of atomisation and enthalpy change of neutralisation
- ☐ **B** enthalpy change of atomisation and enthalpy change of solution
- ☐ **C** enthalpy change of combustion and enthalpy change of hydration
- ☐ **D** enthalpy change of solution and enthalpy change of hydration

**(Total for Question 1 = 1 mark)**

**2.** Ammonia is made by the Haber process. The reactants are nitrogen and hydrogen.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H \text{ is negative}$$

What will **increase** the rate of the forward reaction?

- ☐ **A** adding argon to the mixture but keeping the total volume constant
- ☐ **B** decreasing the temperature
- ☐ **C** increasing the total pressure by reducing the total volume at constant temperature
- ☐ **D** removing ammonia as it is made but keeping the total volume of the mixture the same

**(Total for Question 2 = 1 mark)**

**3.** $AgNO_3(aq)$ is added to a solution of a halide ion, $X^-(aq)$, and aqueous ammonia is then added. The ionic equations for the two reactions that occur are shown.

$$Ag^+(aq) + X^-(aq) \rightleftharpoons AgX(s) \qquad \text{equilibrium } \mathbf{1}$$

$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad \text{equilibrium } \mathbf{2}$$

Which statement is **correct**?

- ☐ **A** The position of equilibrium **1** lies to the left when $X^- = I^-$.
- ☐ **B** Increasing the concentration of ammonia causes the position of equilibrium 1 to move to the left.
- ☐ **C** $K_c$ for equilibrium **2** is larger when $X^- = Cl^-$ than when $X^- = I^-$.
- ☐ **D** Equilibrium **2** is a redox reaction.

**(Total for Question 3 = 1 mark)**

**4.** Equal amounts of W and X are mixed and allowed to reach equilibrium.

$$W + X \rightleftharpoons Y + Z$$

The value of the equilibrium constant $K_c = 4.85$.
At equilibrium, the mixture will contain

☒ **A** almost all Y and Z
☒ **B** almost all W and X
☒ **C** W, X, Y and Z but there is less Y and Z than W and X
☒ **D** W, X, Y and Z but there is more Y and Z than W and X

**(Total for Question 4 = 1 mark)**

**5.** A student carried out an experiment to determine the equilibrium constant for the reaction to form ethyl ethanoate from ethanol and ethanoic acid.

$$CH_3COOH + CH_3CH_2OH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$$

Different amounts of each substance were added to conical flasks, each containing 2.0 $cm^3$ of 1.0 $mol.dm^{-3}$ hydrochloric acid as shown in the table.

| Conical flask | Volume added / $cm^3$ | | | | |
|---|---|---|---|---|---|
| | HCl (aq) | $H_2O$ (l) | $CH_3COOH$ (l) | $CH_3COOCH_2CH_3$ (l) | $CH_3CH_2OH$ (l) |
| 1 | 2.0 | 1.0 | 0 | 2.0 | 0 |
| 2 | 2.0 | 0 | 5.0 | 0 | 5.0 |
| 3 | 2.0 | 0 | 4.0 | 0 | 3.0 |
| 4 | 2.0 | 0 | 0 | 3.0 | 0 |

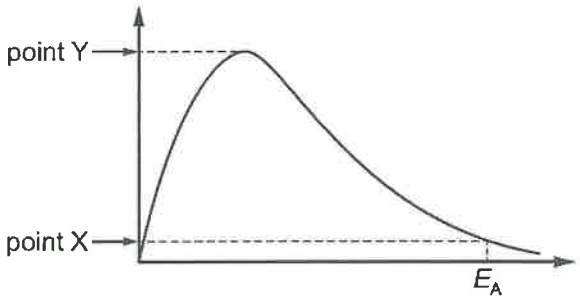
The flasks were then stoppered and left for a week to reach equilibrium.

In which flask(s) was the equilibrium approached from the **right-hand** side of the equation?

☒ **A** flask 1 only
☒ **B** flask 4 only
☒ **C** flasks 1 and 4 only
☒ **D** flasks 2 and 3 only

**(Total for Question 5 = 1 mark)**

**6.** The diagram shows a Boltzmann distribution curve. The axes are not labelled.




Points X and Y are points on the vertical axis.

What is represented by both points X and Y?

| | point X | point Y |
|---|---|---|
| ☐ **A** | number of molecules with energy equal to $E_A$ | largest number of molecules with the same energy |
| ☐ **B** | number of molecules with energy equal to or greater than $E_A$ | largest number of molecules with the same energy |
| ☐ **C** | number of molecules with energy equal to $E_A$ | the amount of energy of the greatest number of molecules |
| ☐ **D** | number of molecules with energy equal to or greater than $E_A$ | the amount of energy of the greatest number of molecules |

**(Total for Question 6 = 1 mark)**

**7.** Lattice energy is the energy change when one mole of an ionic solid is formed from its gaseous ions.

(a) Which compound has the most exothermic lattice energy?

(1)

☒ **A** MgO
☒ **B** MgS
☒ **C** CaO
☒ **D** CaS

(b) Which of these compounds has the greatest difference between the experimental (Born-Haber) lattice energy and the theoretical value obtained using electrostatic theory?

(1)

☒ **A** LiF
☒ **B** LiI
☒ **C** NaF
☒ **D** NaI

**(Total for Question 7 = 2 marks)**

**8.** Energy changes are used in the Born-Haber cycle to calculate the lattice energy of sodium oxide, $Na_2O$.
Which of these has a **negative** value?

☒ **A** enthalpy change of atomisation of sodium
☒ **B** first ionisation energy of sodium
☒ **C** first electron affinity of oxygen
☒ **D** second electron affinity of oxygen

**(Total for Question 8 = 1 mark)**

**9.** What is the equation for the first electron affinity of sulfur?

☒ **A** $S(g) \rightarrow S^+(g) + e^-$
☒ **B** $S(g) + e^- \rightarrow S^-(g)$
☒ **C** $S(g) + 2e^- \rightarrow S^{2-}(g)$
☒ **D** $S^-(g) + e^- \rightarrow S^{2-}(g)$

**(Total for Question 9 = 1 mark)**

**10.** A two-step reaction is shown.

$$H_2O_2(aq) + I^-(aq) \rightarrow H_2O(l) + OI^-(aq)$$
$$H_2O_2(aq) + OI^-(aq) \rightarrow H_2O(l) + O_2(g) + I^-(aq)$$

(a) What is the role of $I^-(aq)$ in the overall reaction?

(1)

☒ **A** heterogeneous catalyst
☒ **B** homogeneous catalyst
☒ **C** oxidising agent
☒ **D** product

(b) Which is the equation for the overall reaction?

(1)

☒ **A** $2H_2O_2(aq) + I^-(aq) + OI^-(aq) \rightarrow 2H_2O(l) + OI^-(aq) + I^-(aq) + O_2(g)$
☒ **B** $2H_2O_2(aq) + OI^-(aq) \rightarrow 2H_2O(l) + OI^-(aq) + O_2(g)$
☒ **C** $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
☒ **D** $2H_2O_2(aq) + 2I^-(aq) \rightarrow 2H_2O(l) + OI^-(aq) + I^-(aq) + \frac{1}{2}O_2(g)$

**(Total for Question 10 = 2 marks)**

**11.** Which of these changes has the largest **increase** in the entropy of the system?

☒ **A** $H_2O(s) \rightarrow H_2O(l)$
☒ **B** $Hg(l) \rightarrow Hg(g)$
☒ **C** $C(graphite) \rightarrow C(diamond)$
☒ **D** $H_2O(l) + HCl(g) \rightarrow H_3O^+(aq) + Cl^-(aq)$

**(Total for Question 11 = 1 mark)**

**12.** Which of these gases would have the greatest standard molar entropy?

☒ **A** $H_2$
☒ **B** $N_2$
☒ **C** $NH_3$
☒ **D** $SO_2$

**(Total for Question 12 = 1 mark)**

**13.** Which expression relates entropy and equilibrium constant?

- ☒ **A** $\Delta S_{total} = -R\,lnK$
- ☒ **B** $\Delta S_{total} = R\,lnK$
- ☒ **C** $\Delta S_{sys} = -R\,lnK$
- ☒ **D** $\Delta S_{sys} = R\,lnK$

**(Total for Question 13 = 1 mark)**

**14.** This question is about sodium chloride.

(a) Sodium chloride dissolves in water.

$$NaCl(s) + (aq) \rightarrow Na^+(aq) + Cl^-(aq) \qquad \Delta_{sol}H(NaCl) = +1.0\ kJ.mol^{-1}$$

In aqueous medium, the sodium ions and the chloride ions are attracted to water via

(1)

- ☒ **A** hydrogen bond
- ☒ **B** london forces
- ☒ **C** ion – dipole attraction
- ☒ **D** london forces and hydrogen bond

(b) The dissolving of sodium chloride in water is thermodynamically feasible.
What may be deduced from this statement and the data in part (a)?

(1)

- ☒ **A** the activation energy for the reaction is small
- ☒ **B** the enthalpy change for $\Delta_{hyd}H(Na^+)$ is positive
- ☒ **C** the reaction has a positive entropy change of the surroundings
- ☒ **D** the reaction has a positive entropy change of the system

**(Total for Question 14 = 2 marks)**

**15.** What is the similarity between 20 $cm^3$ of 0.05 $mol.dm^{-3}$ $H_2SO_4(aq)$ and 20 $cm^3$ of 0.10 $mol.dm^{-3}$ $CH_3COOH(aq)$?

- ☒ **A** they have the same pH
- ☒ **B** they have the same total concentration of ions
- ☒ **C** they have the same total concentration of negative ions
- ☒ **D** they are neutralised by 20 $cm^3$ of 0.10 $mol.dm^{-3}$ NaOH(aq)

**(Total for Question 15 = 1 mark)**

**16.** What is the conjugate base of $HSO_4^-$?

- ☒ **A** $H_2SO_4$
- ☒ **B** $H_3SO_4^+$
- ☒ **C** $SO_4^{2-}$
- ☒ **D** $SO_3^-$

**(Total for Question 16 = 1 mark)**

**17.** What is the pH of the solution formed when 50 $cm^3$ of 0.010 $mol.dm^{-3}$ HCl(aq) is mixed with 50 $cm^3$ of 0.010 $mol.dm^{-3}$ $HNO_3$(aq)?

- ☒ **A** 1.0
- ☒ **B** 1.7
- ☒ **C** 2.0
- ☒ **D** 2.3

**(Total for Question 17 = 1 mark)**

**18.** Which concentration of aqueous calcium hydroxide has a pH of 12.32?
$K_w = 1.00 \times 10^{-14}$ $mol^2.dm^{-6}$

- ☒ **A** $4.79 \times 10^{-13}$ $mol.dm^{-3}$
- ☒ **B** $1.04 \times 10^{-2}$ $mol\ dm^{-3}$
- ☒ **C** $2.09 \times 10^{-2}$ $mol.dm^{-3}$
- ☒ **D** $2.09 \times 10^{12}$ $mol.dm^{-3}$

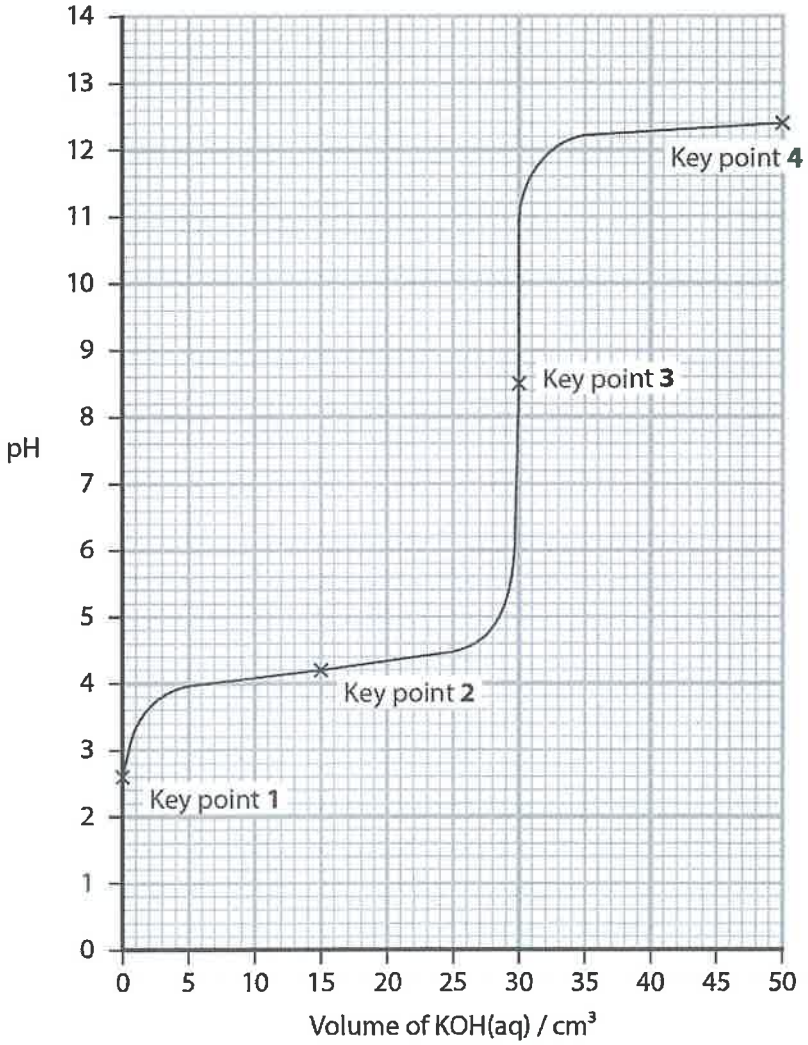
**(Total for Question 18 = 1 mark)**

**19.** The pH of pure water is 7.0 at 25 °C and 6.6 at 50 °C.
Which of these statements is **not** true?

- ☒ **A** pure water is acidic at 50 °C
- ☒ **B** in pure water, $[H^+] = [OH^-]$ at any temperature
- ☒ **C** in pure water, $[H^+]$ is greater at 50 °C than at 25 °C
- ☒ **D** $K_w$ is greater at 50 °C than at 25 °C

**(Total for Question 19 = 1 mark)**

**20.** A titration curve for the reaction of 0.100 $mol.dm^{-3}$ methanoic acid, HCOOH, with 0.040 $mol.dm^{-3}$ potassium hydroxide, KOH, is shown.




(a) The solution formed when methanoic acid and potassium hydroxide are mixed at equal ration, has a pH value of

(1)

☒ **A** pH = 2.50
☒ **B** pH = 4.20
☒ **C** pH = 8.50
☒ **D** pH = 12.40

(b) What volume, in $cm^3$, of methanoic acid was used in this titration?

(1)

☒ **A** 12.0
☒ **B** 15.0
☒ **C** 30.0
☒ **D** 75.0

(c) Which expression about the concentration of hydroxide ions, $[OH^-]$, at Key point 4 is correct?

(1)

☒ **A** $[OH^-] = 0.040$
☒ **B** $[OH^-] > 0.040$
☒ **C** $[OH^-] < 0.040$
☒ **D** $[OH^-] = 10^{-12.4}$

**(Total for Question 20 = 3 marks)**

**TOTAL FOR SECTION A = 25 MARKS**

## SECTION B

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

**21.** Ethanoic acid, $CH_3COOH$, is the carboxylic acid found in vinegar.
Carboxylic acids are weak acids.
The table gives some data for four carboxylic acids.

| Name | $pk_a$ | $K_a$/mol.dm$^{-3}$ |
|---|---|---|
| Butanoic acid | - | $1.51 \times 10^{-5}$ |
| Ethanoic acid | - | $1.74 \times 10^{-5}$ |
| Methanoic acid | 3.75 | - |
| Propanoic acid | 4.88 | - |

(a)(i) State what is meant by the term **weak acid**.

(2)

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(ii) Explain which of these four compounds is the strongest acid, using the data in the table.

(3)

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(iii) Under certain conditions, ethanoic acid could react with propanoic acid in an acid-base reaction.
Complete the equation giving the products of this reaction and identifying the acid-base conjugate pairs in the spaces below the equation.

(2)

$CH_3COOH + CH_3CH_2COOH \rightarrow$ ..... + .....

..... ..... ..... .....

(b) Calculate the pH of a solution of 0.100 $mol.dm^{-3}$ ethanoic acid.
You must include any assumptions you have made.

(5)

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**(Total for Question 21 = 12 marks)**

**22.** This question is about the solubility of chloride salts.

The enthalpy change of solution may be found by dissolving a compound in deionised water and measuring the temperature change.

A student devised an experiment to measure the enthalpy change of solution for barium chloride, $BaCl_2$.

The method resulted in the formation of 50.0 $cm^3$ of solution containing 8.0 g of barium chloride. The enthalpy change of solution was found to be –32 $kJ.mol^{-1}$.

(a) Calculate the temperature increase obtained by the student in this experiment.

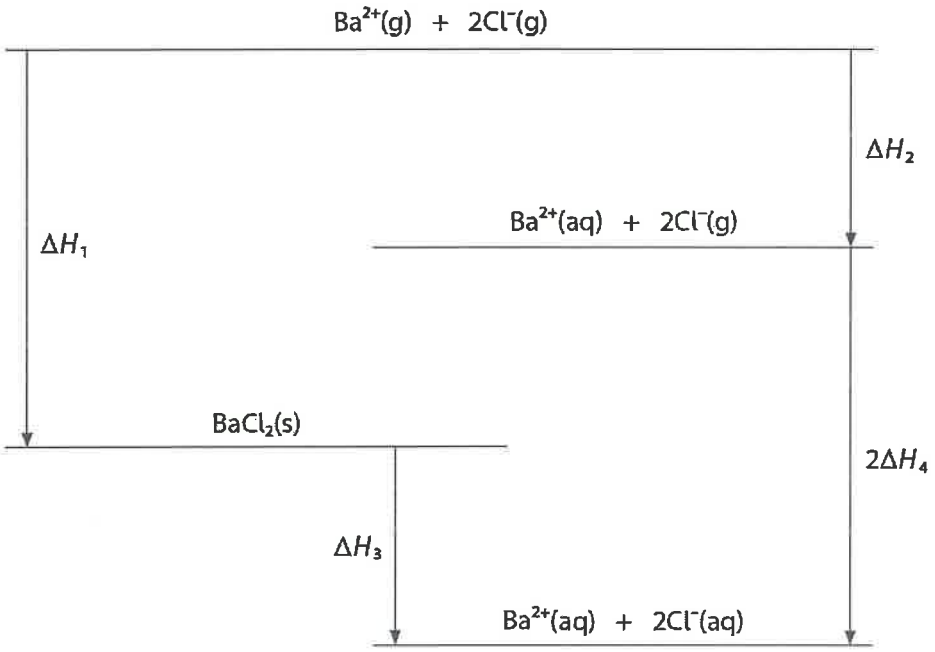
**Given**: $M_r$ of $BaCl_2 = 208.3$

specific heat capacity of the solution, $c = 4.18\ J.g^{-1}.°C^{-1}$

The energy transferred, in Joules, $E = m.c.\Delta T$

(3)

(b) The energy level diagram shows the enthalpy changes associated with the formation of barium chloride solution.




Some of the data for this energy level diagram is shown in the table.

| Symbol | Enthalpy change | Value / kJ.mol$^{-1}$ |
|---|---|---|
| $\Delta H_1$ | | –2056 |
| $\Delta H_2$ | Enthalpy change of hydration of $Ba^{2+}$ | –1360 |
| $\Delta H_3$ | Enthalpy change of solution of $BaCl_2$ | –32 |
| $\Delta H_4$ | | |

(i) Complete the enthalpy change column of the table by giving the names of the enthalpy changes $\Delta H_1$ and $\Delta H_4$

(2)

(ii) Calculate a value for the enthalpy change $\Delta H_4$.

(2)

(c) At 298 K, 0.270 g of calcium sulfate will dissolve in 100 $cm^3$ of water to form a saturated solution.
Adding more calcium sulfate results in an equilibrium between a saturated solution and undissolved calcium sulfate.

$$CaSO_4(s) \rightleftharpoons Ca^{2+}(aq) + SO_4^{2-}(aq)$$

The expression for the equilibrium constant for this equilibrium is shown.

$$K_{c1} = [Ca^{2+}(aq)][SO_4^{2-}(aq)]$$

(i) State why the concentration of calcium sulfate is not present in the $Kc_1$ expression.

(1)

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(ii) Calculate the concentration, in mol.$dm^{-3}$, of calcium sulfate solution when 0.270 g dissolves in water to produce 100 $cm^3$ of solution.

(1)

(iii) Calculate the value of $K_{c1}$
Give units with your answer.

(2)

(d) Like most ionic compounds, the solubility of calcium sulfate changes with temperature and so the equilibrium constant also changes.
The equilibrium constants at 298 K and 350 K are related mathematically by the simplified equation shown.

$$\log_{10}K_{c2} - \log_{10}K_{c1} = \Delta_{sol}H \times 2.61 \times 10^{-5}$$

**Data**
$K_{c1}$ is the equilibrium constant at 298 K
$K_{c2}$ is the equilibrium constant at 350 K
$\Delta_{sol}H$ is the enthalpy change of solution of $CaSO_4 = -17\ 800\ J.mol^{-1}$
and at $T_1 = 298$ K, $K_{c1}$ is the answer to (c)(iii)

(i) Calculate a value for the equilibrium constant at 350 K, $K_{c2}$, using your answer to (c)(iii) and the simplified mathematical expression.

[If you have been unable to calculate a value for $Kc_1$ then you may use $K_{c1} = 6.50 \times 10^{-6}$. This is not the correct value.]

(4)

(ii) Deduce how the solubility of calcium sulfate changes as temperature is increased. Justify your answer in terms of $K_c$ values.

(2)

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**(Total for Question 22 = 17 marks)**

**23.** The Ostwald process is used in the manufacture of nitric acid, $HNO_3$. There are three stages:

Stage **1** oxidation of ammonia to nitrogen monoxide, NO, at 1200 K
Stage **2** oxidation of NO to nitrogen dioxide, $NO_2$
Stage **3** reaction of $NO_2$ with water to produce $HNO_3$.

(a) The equation for the reaction in Stage **1** is shown.

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad \Delta H = -905 \text{ kJ.mol}^{-1}$$

The catalyst **only** requires heating at the start. Suggest one possible reason for this.

(1)

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(b) The equation for Stage **2** is shown.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

The initial rate of this reaction was determined for different concentrations and the results are shown.

| Experiment | Initial concentration / mol.dm$^{-3}$ | | Initial rate / mol.dm$^{-3}$.s$^{-1}$ |
|---|---|---|---|
| | [NO(g)] | [$O_2$(g)] | |
| 1 | 0.0250 | 0.0100 | $5.10 \times 10^{-4}$ |
| 2 | 0.0250 | 0.0200 | $1.02 \times 10^{-3}$ |
| 3 | 0.0500 | 0.0400 | $8.16 \times 10^{-3}$ |

(i) Deduce the order of reaction with respect to nitrogen monoxide and oxygen.
Justify your answers.

(3)

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***Continue (b)(i) on the next page***

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(ii) Write the rate equation for the reaction in Stage **2**, using your answers to (i).

(1)

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(iii) Calculate the rate constant of this reaction, using values from Experiment 1.
Include units in your answer.

(2)

(c) A two-step mechanism for the reaction in Stage **2** has been proposed.

Step 1 $2NO(g) \rightleftharpoons N_2O_2(g)$

Step 2 $N_2O_2(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

Deduce which is more likely to be the rate determining step, using your answer to (b)(ii).

(2)

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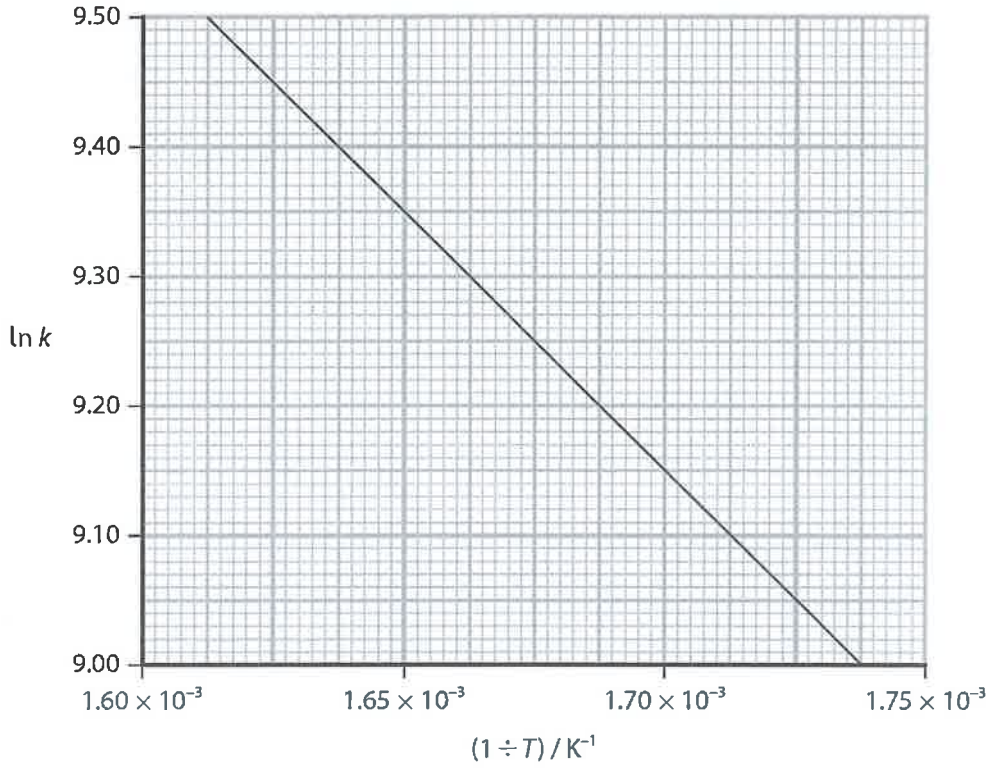
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(d) In Stage **3**, $NO_2$ reacts with water at a ratio of 2:1.
When $NO_2$ is added to water, a mixture of nitric acid and another product, with $K_a = 4.0 \times 10^{-4}$ mol.dm$^{-3}$ is formed.
Write an equation for this reaction.

(1)

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(e) The rate constant for the reaction of nitrogen monoxide with oxygen was determined for a range of temperatures to find the activation energy of the reaction.
A graph is shown.




Calculate the activation energy, Ea, for this reaction, using the Arrhenius equation.
Include a sign and units in your answer.

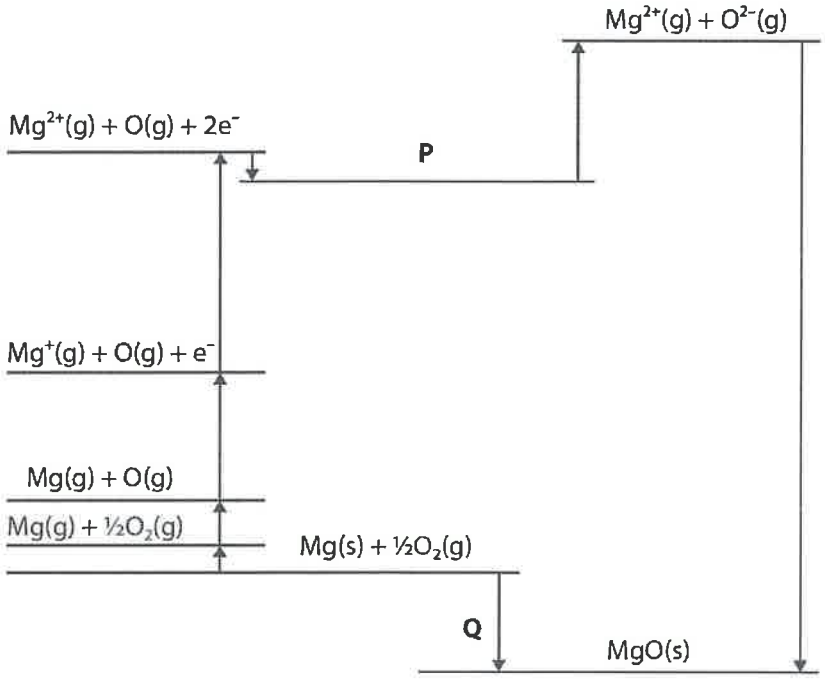
(3)

$$\ln k = -\frac{E_a}{RT} + \text{constant}$$

**(Total for Question 23 = 13 marks)**

**24.** This question is about ionic compounds of magnesium.

(a) An incomplete Born–Haber cycle and relevant data for magnesium oxide are shown.




| Energy change | Value / $kJ.mol^{-1}$ |
|---|---|
| Lattice energy of magnesium oxide | −3795 |
| First electron affinity of oxygen | −141 |
| Second electron affinity of oxygen | +798 |
| First ionisation energy of magnesium | +738 |
| Second ionisation energy of magnesium | +1451 |
| Enthalpy change of atomisation of oxygen | +249 |
| Enthalpy change of atomisation of magnesium | +148 |

(i) Give the formulae and state symbols of the set of particles labelled '**P**'.

(1)

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(ii) Name the energy change **Q**.

(1)

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(iii) Calculate the value of **Q**.
You must show your working. Include a sign and units in your answer.

(2)

(b) The values of the experimental and theoretical lattice energies for magnesium oxide are very similar. However, the values for magnesium sulfide are significantly different.
Explain these two statements.

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**(Total for Question 24 = 8 marks)**

**TOTAL FOR SECTION B = 50 MARKS**

## SECTION C

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

**25. "Exothermic changes can be thermodynamically feasible but prevented by kinetic stability."**

One step in the manufacture of sulfuric acid is an example of these exothermic changes. This step can be represented by the following equation:

$$SO_2(g) + \tfrac{1}{2} O_2(g) \rightleftharpoons SO_3(g)$$

**Data:** At 450°C, $K = 2.82 \times 10^2\ dm^3.mol^{-1}$ $\Delta H^\ominus = -99.0\ kJ.mol^{-1}$

This equilibrium is not reached at a significant rate if a catalyst is not present.
The original catalyst for this process was platinum metal, but this has since been replaced by vanadium(V) oxide.

(a) State what is meant by the term 'dynamic equilibrium'.

(2)

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(b) Use the data in the table to calculate the standard molar entropy change of the system, $\Delta S^\ominus_{system}$, for this reaction at 298 K.

(2)

| Compound | Standard molar entropy, $S^\ominus$ / $J.K^{-1}.mol^{-1}$ |
|---|---|
| $SO_2(g)$ | 248.2 |
| $O_2(g)$ | 205.1 |
| $SO_3(g)$ | 256.8 |

(c) Calculate the total molar entropy change, $\Delta S^{\ominus}_{Total}$, at 298K.
Include a unit and a sign in your answer.

(4)

(d) Deduce the value of $K$ at 298K.

(1)

*(e) On industrial scale, the production of $SO_3(g)$, using the quoted equilibrium, requires a temperature of 450°C, pressure of 2atm and vanadium(V) oxide as a catalyst.
Comment on the bold type statement mentioned at the start of this exercise.
In your answer you should refer to the following:

- The extent of reaction
- The effect, if any, on the value of $K$ when the catalyst is changed from platinum metal to vanadium(V) oxide.
- The conditions used.

(6)

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**(Total for Question 25 = 15 marks)**
**TOTAL FOR SECTION C = 15 MARKS**
**TOTAL FOR PAPER = 90 MARKS**

# The Periodic Table of Elements

| 1 | 2 | | | | | | | | | | | 3 | 4 | 5 | 6 | 7 | 0 (8) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1.0 H hydrogen 1 | | | | | | | | | | (18) 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<br>atomic symbol<br>name<br>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

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Lanthanide series | 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 |
| * Actinide series | 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 |

## 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.** Which pair of enthalpy changes will **always** share the same sign (i.e. both are always exothermic or both are always endothermic)?

- ☐ **A** enthalpy change of atomisation and enthalpy change of neutralisation
- ☐ **B** enthalpy change of atomisation and enthalpy change of solution
- ☒ **C** enthalpy change of combustion and enthalpy change of hydration
- ☐ **D** enthalpy change of solution and enthalpy change of hydration

(1) ✓

**(Total for Question 1 = 1 mark)**

**2.** Ammonia is made by the Haber process. The reactants are nitrogen and hydrogen.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H \text{ is negative}$$

What will **increase** the rate of the forward reaction?

- ☐ **A** adding argon to the mixture but keeping the total volume constant
- ☐ **B** decreasing the temperature
- ☒ **C** increasing the total pressure by reducing the total volume at constant temperature
- ☐ **D** removing ammonia as it is made but keeping the total volume of the mixture the same

(1) ✓

**(Total for Question 2 = 1 mark)**

**3.** $AgNO_3(aq)$ is added to a solution of a halide ion, $X^-(aq)$, and aqueous ammonia is then added. The ionic equations for the two reactions that occur are shown.

$$Ag^+(aq) + X^-(aq) \rightleftharpoons AgX(s) \qquad \text{equilibrium } \mathbf{1}$$

$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad \text{equilibrium } \mathbf{2}$$

Which statement is **correct**?

- ☐ **A** The position of equilibrium **1** lies to the left when $X^- = I^-$.
- ☒ **B** Increasing the concentration of ammonia causes the position of equilibrium 1 to move to the left.
- ☐ **C** $K_c$ for equilibrium **2** is larger when $X^- = Cl^-$ than when $X^- = I^-$.
- ☐ **D** Equilibrium **2** is a redox reaction.

(1) ✓

**(Total for Question 3 = 1 mark)**

**4.** Equal amounts of W and X are mixed and allowed to reach equilibrium.

$$W + X \rightleftharpoons Y + Z$$

The value of the equilibrium constant $K_c = 4.85$.
At equilibrium, the mixture will contain

- ☒ **A** almost all Y and Z
- ☒ **B** almost all W and X
- ☒ **C** W, X, Y and Z but there is less Y and Z than W and X
- ☒ **D** W, X, Y and Z but there is more Y and Z than W and X

(1) ✓

**(Total for Question 4 = 1 mark)**

**5.** A student carried out an experiment to determine the equilibrium constant for the reaction to form ethyl ethanoate from ethanol and ethanoic acid.

$$CH_3COOH + CH_3CH_2OH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$$

Different amounts of each substance were added to conical flasks, each containing 2.0 $cm^3$ of 1.0 $mol.dm^{-3}$ hydrochloric acid as shown in the table.

| Conical flask | Volume added / $cm^3$ | | | | |
|---|---|---|---|---|---|
| | HCl (aq) | $H_2O$ (l) | $CH_3COOH$ (l) | $CH_3COOCH_2CH_3$ (l) | $CH_3CH_2OH$ (l) |
| 1 | 2.0 | 1.0 | 0 | 2.0 | 0 |
| 2 | 2.0 | 0 | 5.0 | 0 | 5.0 |
| 3 | 2.0 | 0 | 4.0 | 0 | 3.0 |
| 4 | 2.0 | 0 | 0 | 3.0 | 0 |

The flasks were then stoppered and left for a week to reach equilibrium.

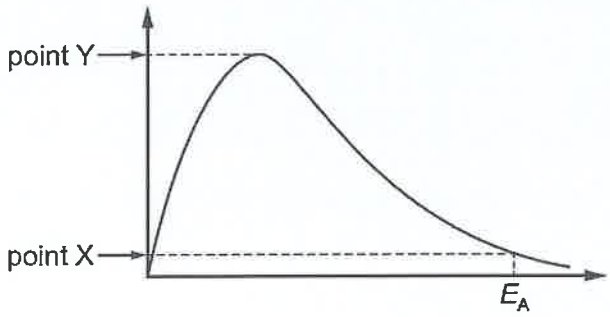
In which flask(s) was the equilibrium approached from the **right-hand** side of the equation?

- ☒ **A** flask 1 only
- ☒ **B** flask 4 only
- ■ **C** flasks 1 and 4 only
- ☒ **D** flasks 2 and 3 only

(1) ✓

**(Total for Question 5 = 1 mark)**

**6.** The diagram shows a Boltzmann distribution curve. The axes are not labelled.




Points X and Y are points on the vertical axis.

What is represented by both points X and Y?

| | | point X | point Y |
|---|---|---|---|
| ☒ | **A** | number of molecules with energy equal to $E_A$ | largest number of molecules with the same energy |
| ☐ | **B** | number of molecules with energy equal to or greater than $E_A$ | largest number of molecules with the same energy |
| ☐ | **C** | number of molecules with energy equal to $E_A$ | the amount of energy of the greatest number of molecules |
| ☐ | **D** | number of molecules with energy equal to or greater than $E_A$ | the amount of energy of the greatest number of molecules |

(1) ✓

**(Total for Question 6 = 1 mark)**

**7.** Lattice energy is the energy change when one mole of an ionic solid is formed from its gaseous ions.

(a) Which compound has the most exothermic lattice energy?

(1)

(1) ✓

- ☒ **A** MgO
- ☐ **B** MgS
- ☐ **C** CaO
- ☐ **D** CaS

(b) Which of these compounds has the greatest difference between the experimental (Born-Haber) lattice energy and the theoretical value obtained using electrostatic theory?

(1)

(1) ✓

- ☐ **A** LiF
- ☒ **B** LiI
- ☐ **C** NaF
- ☐ **D** NaI

**(Total for Question 7 = 2 marks)**

**8.** Energy changes are used in the Born-Haber cycle to calculate the lattice energy of sodium oxide, $Na_2O$.
Which of these has a **negative** value?

(1) ✓

- ☐ **A** enthalpy change of atomisation of sodium
- ☐ **B** first ionisation energy of sodium
- ☒ **C** first electron affinity of oxygen
- ☐ **D** second electron affinity of oxygen

**(Total for Question 8 = 1 mark)**

**9.** What is the equation for the first electron affinity of sulfur?

(1) ✓

- ☐ **A** $S(g) \rightarrow S^+(g) + e^-$
- ☒ **B** $S(g) + e^- \rightarrow S^-(g)$
- ☐ **C** $S(g) + 2e^- \rightarrow S^{2-}(g)$
- ☐ **D** $S^-(g) + e^- \rightarrow S^{2-}(g)$

**(Total for Question 9 = 1 mark)**

**10.** A two-step reaction is shown.

$$H_2O_2(aq) + I^-(aq) \rightarrow H_2O(l) + OI^-(aq)$$
$$H_2O_2(aq) + OI^-(aq) \rightarrow H_2O(l) + O_2(g) + I^-(aq)$$

(a) What is the role of $I^-(aq)$ in the overall reaction?

(1)

- ☒ **A** heterogeneous catalyst
- ☒ **B** homogeneous catalyst
- ☒ **C** oxidising agent
- ☒ **D** product

(b) Which is the equation for the overall reaction?

(1)

- ☒ **A** $2H_2O_2(aq) + I^-(aq) + OI^-(aq) \rightarrow 2H_2O(l) + OI^-(aq) + I^-(aq) + O_2(g)$
- ☒ **B** $2H_2O_2(aq) + OI^-(aq) \rightarrow 2H_2O(l) + OI^-(aq) + O_2(g)$
- ☒ **C** $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
- ☒ **D** $2H_2O_2(aq) + 2I^-(aq) \rightarrow 2H_2O(l) + OI^-(aq) + I^-(aq) + \frac{1}{2}O_2(g)$

**(Total for Question 10 = 2 marks)**

**11.** Which of these changes has the largest **increase** in the entropy of the system?

- ☒ **A** $H_2O(s) \rightarrow H_2O(l)$
- ☒ **B** $Hg(l) \rightarrow Hg(g)$
- ☒ **C** $C(graphite) \rightarrow C(diamond)$
- ☒ **D** $H_2O(l) + HCl(g) \rightarrow H_3O^+(aq) + Cl^-(aq)$

**(Total for Question 11 = 1 mark)**

**12.** Which of these gases would have the greatest standard molar entropy?

- ☒ **A** $H_2$
- ☒ **B** $N_2$
- ☒ **C** $NH_3$
- ☒ **D** $SO_2$

**(Total for Question 12 = 1 mark)**

**13.** Which expression relates entropy and equilibrium constant?

- ☐ **A** $\Delta S_{total} = -R\,lnK$
- ☒ **B** $\Delta S_{total} = R\,lnK$
- ☐ **C** $\Delta S_{sys} = -R\,lnK$
- ☐ **D** $\Delta S_{sys} = R\,lnK$

**(Total for Question 13 = 1 mark)**

**14.** This question is about sodium chloride.

(a) Sodium chloride dissolves in water.

$$NaCl(s) + (aq) \rightarrow Na^+(aq) + Cl^-(aq) \qquad \Delta_{sol}H(NaCl) = +1.0\ kJ.mol^{-1}$$

In aqueous medium, the sodium ions and the chloride ions are attracted to water via

(1)

- ☐ **A** hydrogen bond
- ☐ **B** london forces
- ☒ **C** ion – dipole attraction
- ☐ **D** london forces and hydrogen bond

(b) The dissolving of sodium chloride in water is thermodynamically feasible.
What may be deduced from this statement and the data in part (a)?

(1)

- ☐ **A** the activation energy for the reaction is small
- ☐ **B** the enthalpy change for $\Delta_{hyd}H(Na^+)$ is positive
- ☒ **C** the reaction has a positive entropy change of the surroundings
- ☐ **D** the reaction has a positive entropy change of the system

**(Total for Question 14 = 2 marks)**

**15.** What is the similarity between 20 $cm^3$ of 0.05 $mol.dm^{-3}$ $H_2SO_4(aq)$ and 20 $cm^3$ of 0.10 $mol.dm^{-3}$ $CH_3COOH(aq)$?

- ☐ **A** they have the same pH
- ☐ **B** they have the same total concentration of ions
- ☐ **C** they have the same total concentration of negative ions
- ☒ **D** they are neutralised by 20 $cm^3$ of 0.10 $mol.dm^{-3}$ NaOH(aq)

**(Total for Question 15 = 1 mark)**

**16.** What is the conjugate base of $HSO_4^-$?

- ☒ **A** $H_2SO_4$
- ☒ **B** $H_3SO_4^+$
- ☒ **C** $SO_4^{2-}$
- ☒ **D** $SO_3^-$

**(Total for Question 16 = 1 mark)**

**17.** What is the pH of the solution formed when 50 $cm^3$ of 0.010 $mol.dm^{-3}$ HCl(aq) is mixed with 50 $cm^3$ of 0.010 $mol.dm^{-3}$ $HNO_3$(aq)?

- ☒ **A** 1.0
- ☒ **B** 1.7
- ☒ **C** 2.0
- ☒ **D** 2.3

**(Total for Question 17 = 1 mark)**

**18.** Which concentration of aqueous calcium hydroxide has a pH of 12.32?
$K_w = 1.00 \times 10^{-14}$ $mol^2.dm^{-6}$

- ☒ **A** $4.79 \times 10^{-13}$ $mol.dm^{-3}$
- ☒ **B** $1.04 \times 10^{-2}$ $mol\ dm^{-3}$
- ☒ **C** $2.09 \times 10^{-2}$ $mol.dm^{-3}$
- ☒ **D** $2.09 \times 10^{12}$ $mol.dm^{-3}$

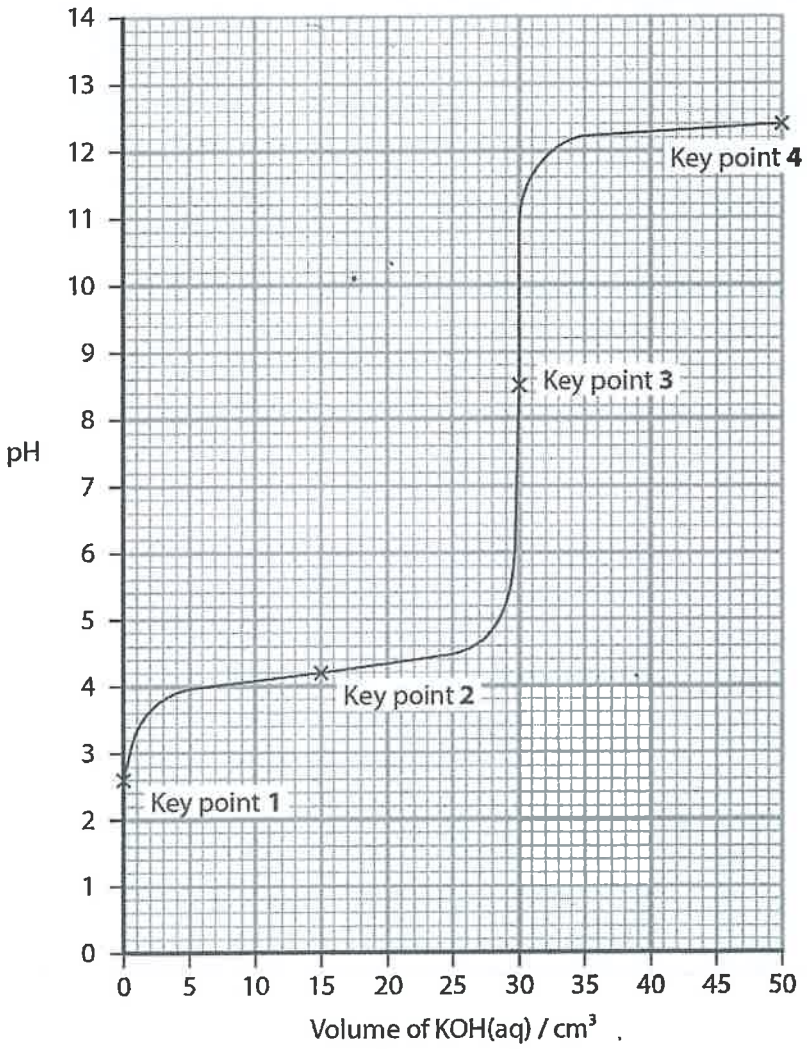
**(Total for Question 18 = 1 mark)**

**19.** The pH of pure water is 7.0 at 25 °C and 6.6 at 50 °C.
Which of these statements is **not** true?

- ☒ **A** pure water is acidic at 50 °C
- ☒ **B** in pure water, $[H^+] = [OH^-]$ at any temperature
- ☒ **C** in pure water, $[H^+]$ is greater at 50 °C than at 25 °C
- ☒ **D** $K_w$ is greater at 50 °C than at 25 °C

**(Total for Question 19 = 1 mark)**

**20.** A titration curve for the reaction of 0.100 mol.dm$^{-3}$ methanoic acid, HCOOH, with 0.040 mol.dm$^{-3}$ potassium hydroxide, KOH, is shown.




(a) The solution formed when methanoic acid and potassium hydroxide are mixed at equal ration, has a pH value of

(1)

☒ **A** pH = 2.50
☒ **B** pH = 4.20
■ **C** pH = 8.50
☒ **D** pH = 12.40

(1) ✓

(b) What volume, in $cm^3$, of methanoic acid was used in this titration?

(1)

(1) ✓

☒ **A** 12.0
☒ **B** 15.0
☒ **C** 30.0
☒ **D** 75.0

(c) Which expression about the concentration of hydroxide ions, $[OH^-]$, at Key point 4 is correct?

(1)

☒ **A** $[OH^-] = 0.040$
☒ **B** $[OH^-] > 0.040$
(1) ✓ ☒ **C** $[OH^-] < 0.040$
☒ **D** $[OH^-] = 10^{-12.4}$

**(Total for Question 20 = 3 marks)**

**TOTAL FOR SECTION A = 25 MARKS**

## SECTION B

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

**21.** Ethanoic acid, $CH_3COOH$, is the carboxylic acid found in vinegar.
Carboxylic acids are weak acids.
The table gives some data for four carboxylic acids.

| Name | $pk_a$ | $K_a$/mol.dm$^{-3}$ |
|---|---|---|
| Butanoic acid | - | $1.51 \times 10^{-5}$ |
| Ethanoic acid | - | $1.74 \times 10^{-5}$ |
| Methanoic acid | 3.75 | - |
| Propanoic acid | 4.88 | - |

(a)(i) State what is meant by the term **weak acid**. (2)

A weak acid is a compound that dissociates partially (1) in water, forming $H_3O^+$ ions. (1)

(ii) Explain which of these four compounds is the strongest acid, using the data in the table. (3)

Acids' strength is determined by their ability to dissociate in $H_2O$, which is represented by the magnitude of the equilibrium constant, $k_a$. (1)
The higher the value of $k_a$, the stronger the acid is. The two missing $k_a$ values are: (1)
$k_a$ (methanoic) $= 1.78 \times 10^{-4}$ & $k_a$ (propanoic) $= 1.32 \times 10^{-5}$
Hence, methanoic acid is the strongest acid of these four compounds. (1)

(iii) Under certain conditions, ethanoic acid could react with propanoic acid in an acid-base reaction.
Complete the equation giving the products of this reaction and identifying the acid-base conjugate pairs in the spaces below the equation.

(2)

$CH_3COOH + CH_3CH_2COOH \rightarrow$ $CH_3COO^-$ + $CH_3CH_2COOH_2^+$ (1)

Acid 1 Base 2 Base 1 Acid 2 (1)

(b) Calculate the pH of a solution of 0.100 $mol.dm^{-3}$ ethanoic acid.
You must include any assumptions you have made.

(5)

$$K_a = \frac{[CH_3COO^-]_{eqm} \times [H^+]_{eqm}}{[CH_3COOH]_{eqm}}$$ (1)

using assumptions ① & ② ;

$[H^+] = \sqrt{K_a \times [CH_3COOH]_0} = \sqrt{1.74 \times 10^{-5} \times 10^{-1}} = 1.32 \times 10^{-3}$ $mol.dm^{-3}$ (1)

$\Rightarrow$ pH = 2.88 (1)

$CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$

Assumptions :

① The dissociation of $H_2O$ is too small to be considered $\Rightarrow$ $[H^+]_{eqm} = [CH_3COO^-]_{eqm}$ (1)

② The degree of conversion of $CH_3COOH$ is small $\Rightarrow$ $[CH_3COOH]_0 = [CH_3COOH]_{eqm}$ (1)

**(Total for Question 21 = 12 marks)**

**22.** This question is about the solubility of chloride salts.

The enthalpy change of solution may be found by dissolving a compound in deionised water and measuring the temperature change.

A student devised an experiment to measure the enthalpy change of solution for barium chloride, $BaCl_2$.

The method resulted in the formation of 50.0 $cm^3$ of solution containing 8.0 g of barium chloride. The enthalpy change of solution was found to be –32 $kJ.mol^{-1}$.

(a) Calculate the temperature increase obtained by the student in this experiment.

**Given**: $M_r$ of $BaCl_2$ = 208.3
specific heat capacity of the solution, c = 4.18 $J.g^{-1}.°C^{-1}$
The energy transferred, in Joules, E = m.c.ΔT

(3)

$$\Delta H = -\frac{E \times 10^{-3}}{n} = -\frac{m.c.\Delta T \times 10^{-3}}{n}$$ (1)

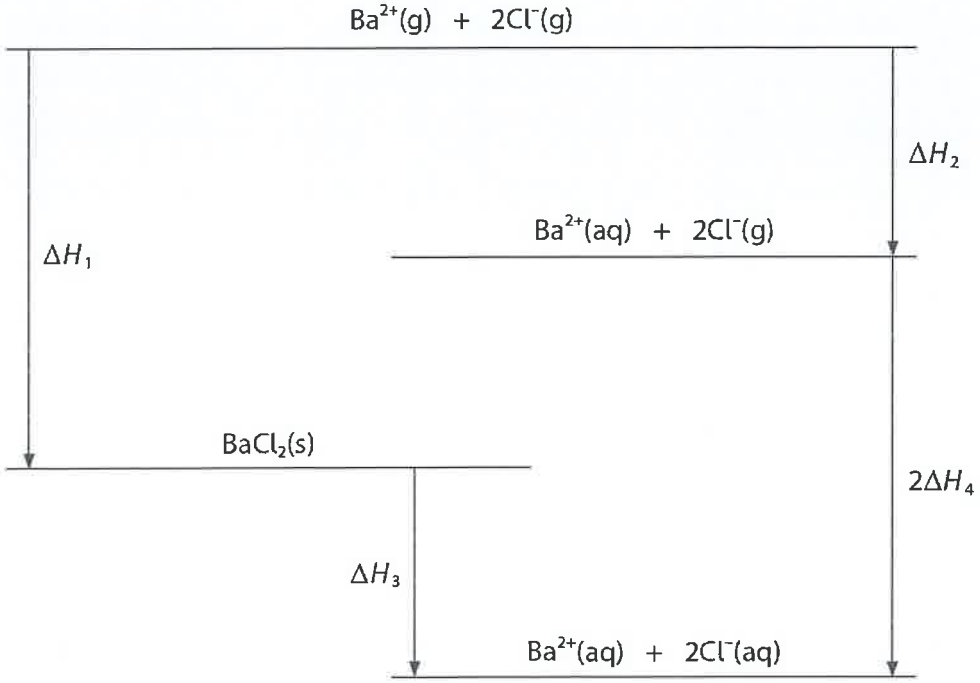
$$\Rightarrow \Delta T = -\frac{\Delta H \times n}{m.c.10^{-3}} = -\frac{\Delta H \times m_{BaCl_2} \times 10^{3}}{m_{solution} \times c \times M_{BaCl_2}}$$ (1)

$$\Rightarrow \Delta T = -\frac{-32 \times 8 \times 10^{3}}{50 \times 4.18 \times 208.3}$$

$$\Rightarrow \Delta T = 5.9°C$$

$$\Rightarrow \Delta T \simeq 6.0°C$$ (1)

(b) The energy level diagram shows the enthalpy changes associated with the formation of barium chloride solution.




Some of the data for this energy level diagram is shown in the table.

| Symbol | Enthalpy change | Value / kJ.mol$^{-1}$ |
|---|---|---|
| $\Delta H_1$ | Lattice Energy ✓(1) | –2056 |
| $\Delta H_2$ | Enthalpy change of hydration of $Ba^{2+}$ | –1360 |
| $\Delta H_3$ | Enthalpy change of solution of $BaCl_2$ | –32 |
| $\Delta H_4$ | Enthalpy change of hydration of $Cl^-$ ✓(1) | |

(i) Complete the enthalpy change column of the table by giving the names of the enthalpy changes $\Delta H_1$ and $\Delta H_4$

(2)

(ii) Calculate a value for the enthalpy change $\Delta H_4$.

(2)

$$\Delta H_1 + \Delta H_3 = \Delta H_2 + 2\Delta H_4 \quad ✓(1)$$

$$\Rightarrow \Delta H_4 = \frac{\Delta H_1 + \Delta H_3 - \Delta H_2}{2} = \frac{-2056 - 32 - (-1360)}{2}$$

$$\Rightarrow \Delta H_4 = -364 \text{ kJ.mol}^{-1} \quad ✓(1)$$

(c) At 298 K, 0.270 g of calcium sulfate will dissolve in 100 $cm^3$ of water to form a saturated solution.
Adding more calcium sulfate results in an equilibrium between a saturated solution and undissolved calcium sulfate.

$$CaSO_4(s) \rightleftharpoons Ca^{2+}(aq) + SO_4^{2-}(aq)$$

The expression for the equilibrium constant for this equilibrium is shown.

$$K_{c1} = [Ca^{2+}(aq)][SO_4^{2-}(aq)]$$

(i) State why the concentration of calcium sulfate is not present in the $Kc_1$ expression.

(1)

Calcium sulfate is solid in this equilibrium. whose density remains constant ✓ (1)

(ii) Calculate the concentration, in $mol.dm^{-3}$, of calcium sulfate solution when 0.270 g dissolves in water to produce 100 $cm^3$ of solution.

(1)

$$[CaSO_{4(aq)}] = \frac{0.270}{136.2 \times 100 \times 10^{-3}}$$ ✓

$$\Rightarrow [CaSO_{4(aq)}] = 1.98 \times 10^{-2} \text{ mol.dm}^{-3}$$ ✓ (1)

(iii) Calculate the value of $K_{c1}$
Give units with your answer.

(2)

$$Kc_1 = (1.98 \times 10^{-2})(1.98 \times 10^{-2})$$

$$= 3.92 \times 10^{-4} \text{ mol}^2.\text{dm}^{-6}$$

✓ (1) ✓ (1)

(d) Like most ionic compounds, the solubility of calcium sulfate changes with temperature and so the equilibrium constant also changes.
The equilibrium constants at 298 K and 350 K are related mathematically by the simplified equation shown.

$$\log_{10}K_{c2} - \log_{10}K_{c1} = \Delta_{sol}H \times 2.61 \times 10^{-5}$$

**Data**
$K_{c1}$ is the equilibrium constant at 298 K
$K_{c2}$ is the equilibrium constant at 350 K
$\Delta_{sol}H$ is the enthalpy change of solution of $CaSO_4 = -17\,800$ J.mol$^{-1}$
and at $T_1 = 298$ K, $K_{c1}$ is the answer to (c)(iii)

(i) Calculate a value for the equilibrium constant at 350 K, $K_{c2}$, using your answer to (c)(iii) and the simplified mathematical expression.

[If you have been unable to calculate a value for $Kc_1$ then you may use $K_{c1} = 6.50 \times 10^{-6}$. This is not the correct value.]

(4)

$\log Kc_2 = \Delta_{sol}H \times 2.61 \times 10^{-5} + \log Kc_1$ ✓ (1)

$\Rightarrow \log Kc_2 = -17800 \times 2.61 \times 10^{-5} + \log(3.92 \times 10^{-4})$

$\Rightarrow \log Kc_2 = -0.46458 - 3.40671$ ✓ (1)

$\Rightarrow \log Kc_2 = -3.87129$ ✓ (1)

$\Rightarrow Kc_2 = 10^{-3.87129} = 1.34 \times 10^{-4}$ ✓ (1)

(ii) Deduce how the solubility of calcium sulfate changes as temperature is increased. Justify your answer in terms of $K_c$ values.

(2)

$Kc_2 < Kc_1 \Rightarrow [ions]_{350K} < [ions]_{298K}$ ✓ (1)

Hence, the solubility of $CaSO_4$ decreases as the temperature increases ✓ (1)

**(Total for Question 22 = 17 marks)**

**23.** The Ostwald process is used in the manufacture of nitric acid, $HNO_3$. There are three stages:

Stage **1** oxidation of ammonia to nitrogen monoxide, NO, at 1200 K
Stage **2** oxidation of NO to nitrogen dioxide, $NO_2$
Stage **3** reaction of $NO_2$ with water to produce $HNO_3$.

(a) The equation for the reaction in Stage **1** is shown.

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad \Delta H = -905 \text{ kJ.mol}^{-1}$$

The catalyst **only** requires heating at the start. Suggest one possible reason for this.

(1)

The reaction is exothermic ✓ which will provide the energy to heat the catalyst.

(b) The equation for Stage **2** is shown.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

The initial rate of this reaction was determined for different concentrations and the results are shown.

| Experiment | Initial concentration / mol.dm$^{-3}$ | | Initial rate / mol.dm$^{-3}$.s$^{-1}$ |
|---|---|---|---|
| | [NO(g)] | [$O_2$(g)] | |
| 1 | 0.0250 | 0.0100 | $5.10 \times 10^{-4}$ |
| 2 | 0.0250 | 0.0200 | $1.02 \times 10^{-3}$ |
| 3 | 0.0500 | 0.0400 | $8.16 \times 10^{-3}$ |

(i) Deduce the order of reaction with respect to nitrogen monoxide and oxygen.
Justify your answers.

(3)

Using experiments 1 & 2, the [NO] is constant, while the $[O_2]$ doubled ✓ so did the rate ✓, hence it's 1st order with respect to $O_2(g)$ ✓ (1).

Using experiments 2 & 3, the [NO] doubled same as the $[O_2]$ ✓ while the rate

*Continue (b)(i) on the next page*

was multiplied by a factor of 8, therefore, when the [NO] doubled the rate quadrupled. Hence, it's of the 2nd order with respect to NO(g) (1)

(ii) Write the rate equation for the reaction in Stage 2, using your answers to (i).

(1)

$r = k[NO]^2[O_2]$ (1)

(iii) Calculate the rate constant of this reaction, using values from Experiment 1.
Include units in your answer.

(2)

$$k = \frac{r}{[NO]^2[O_2]} = \frac{5.10 \times 10^{-4}}{(0.025)^2(0.01)} = 81.6 \text{ mol}^{-2}.\text{dm}^6.\text{s}^{-1}$$ (1)

(c) A two-step mechanism for the reaction in Stage 2 has been proposed.

Step 1 $2NO(g) \rightleftharpoons N_2O_2(g)$

Step 2 $N_2O_2(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

Deduce which is more likely to be the rate determining step, using your answer to (b)(ii).

(2)

The partial orders of the species present in the rate expression represent their molecularity uptill the rate determining step. (1)

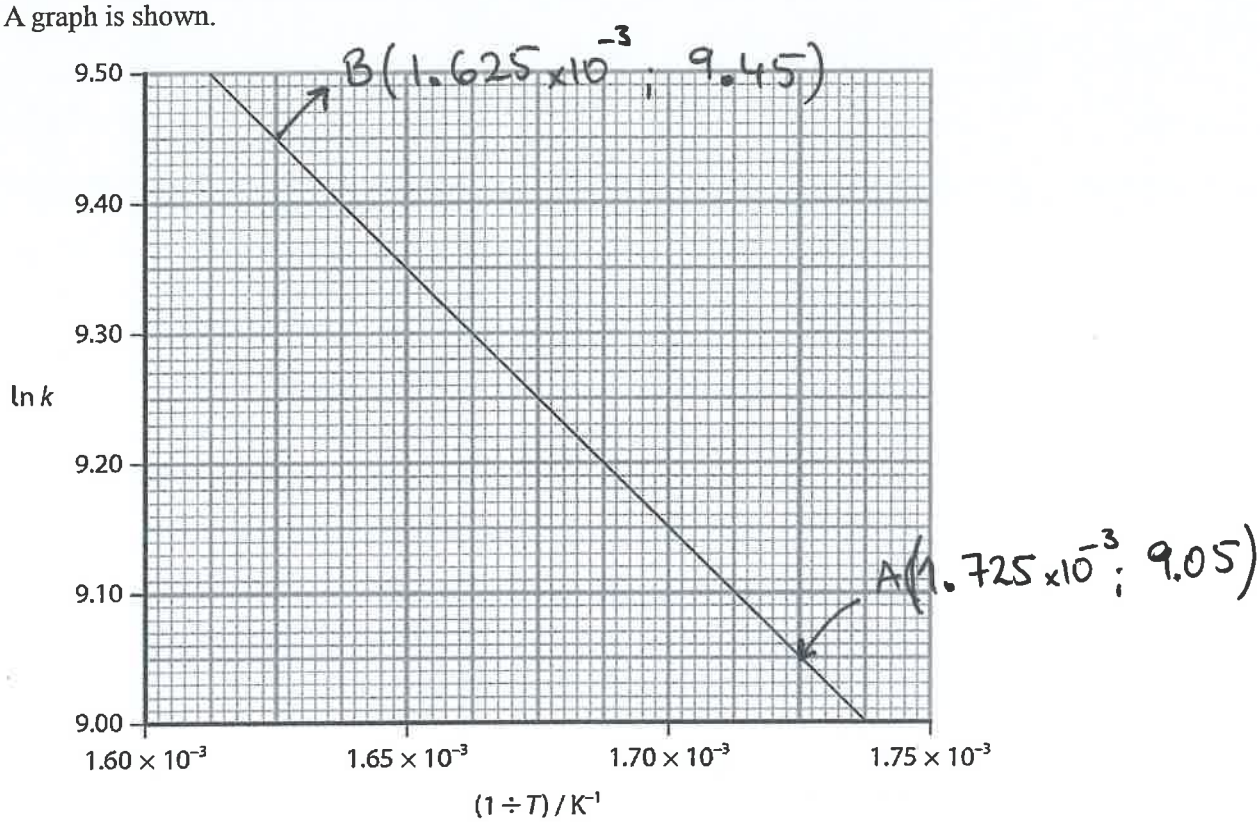
Hence, step 2 is the slow step. (1)

(d) In Stage 3, $NO_2$ reacts with water at a ratio of 2:1.
When $NO_2$ is added to water, a mixture of nitric acid and another product, with $K_a = 4.0 \times 10^{-4}$ mol.dm$^{-3}$ is formed.
Write an equation for this reaction.

(1)

(1) $2NO_2 + H_2O \longrightarrow HNO_3 + HNO_2$

(e) The rate constant for the reaction of nitrogen monoxide with oxygen was determined for a range of temperatures to find the activation energy of the reaction.
A graph is shown.




Calculate the activation energy, Ea, for this reaction, using the Arrhenius equation.
Include a sign and units in your answer.

(3)

$$\ln k = -\frac{E_a}{RT} + \text{constant}$$

$-\frac{Ea}{R} = m \Rightarrow Ea = -m \times R$ ✓ (1)

$\Rightarrow Ea = -\left(\frac{9.45 - 9.05}{1.625 \times 10^{-3} - 1.725 \times 10^{-3}}\right) \times 8.31$ ✓ (1)

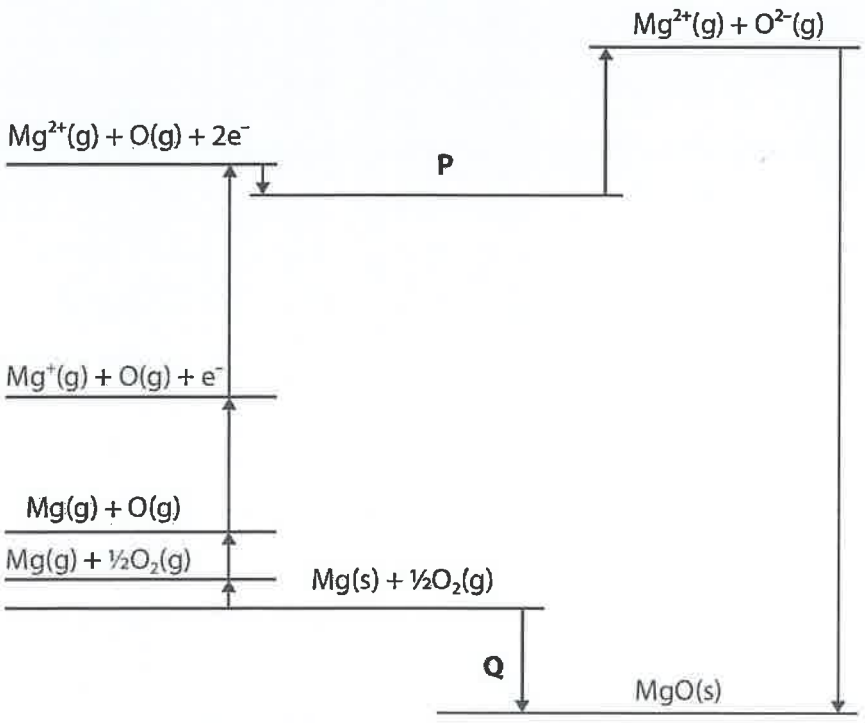
$\Rightarrow Ea = -\left(\frac{0.40 \times 10^{3}}{-0.1}\right) \times 8.31$

$\Rightarrow Ea = +33,240 \text{ J.mol}^{-1}$ or $33 \text{ KJ.mol}^{-1}$ (1)

**(Total for Question 23 = 13 marks)**

**24.** This question is about ionic compounds of magnesium.

(a) An incomplete Born–Haber cycle and relevant data for magnesium oxide are shown.




| Energy change | Value / kJ.mol$^{-1}$ |
|---|---|
| Lattice energy of magnesium oxide | −3795 |
| First electron affinity of oxygen | −141 |
| Second electron affinity of oxygen | +798 |
| First ionisation energy of magnesium | +738 |
| Second ionisation energy of magnesium | +1451 |
| Enthalpy change of atomisation of oxygen | +249 |
| Enthalpy change of atomisation of magnesium | +148 |

(i) Give the formulae and state symbols of the set of particles labelled '**P**'.

(1)

$Mg^{2+}(g) + O^-(g) + e^-$ (1)

(ii) Name the energy change **Q**.

Enthalpy change of formation of MgO (s) (1) (1)

(iii) Calculate the value of **Q**.
You must show your working. Include a sign and units in your answer.

(2)

$Q = 148 + 249 + 738 + 1451 - 141 + 798 - 3795$ (1)

$Q = -552\ kJ.mol^{-1}$ (1)

(b) The values of the experimental and theoretical lattice energies for magnesium oxide are very similar. However, the values for magnesium sulfide are significantly different.
Explain these two statements.

(4)

$Mg^{2+}$ ions have relatively high (1) charge density with a strong polarising effect. (1)
$O^{2-}$ ions are not easily distorted by $Mg^{2+}$ as they have relatively small ionic radius, which explains the similarity in experimental and theoretical L.E values of MgO. (1)
While $S^{2-}$ ions are large enough to be distorted by $Mg^{2+}$, giving MgS a covalent character and hence leading to significantly different (1) L.E values.

**(Total for Question 24 = 8 marks)**

**TOTAL FOR SECTION B = 50 MARKS**

## SECTION C

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

**25. "Exothermic changes can be thermodynamically feasible but prevented by kinetic stability."**

One step in the manufacture of sulfuric acid is an example of these exothermic changes. This step can be represented by the following equation:

$$SO_2(g) + \tfrac{1}{2} O_2(g) \rightleftharpoons SO_3(g)$$

**Data:** At 450°C, $K = 2.82 \times 10^2\ dm^3.mol^{-1}$ $\Delta H^\ominus = -99.0\ kJ.mol^{-1}$

This equilibrium is not reached at a significant rate if a catalyst is not present.
The original catalyst for this process was platinum metal, but this has since been replaced by vanadium(V) oxide.

(a) State what is meant by the term 'dynamic equilibrium'. (2)

A dynamic equilibrium is a phase where both processes of a reversible reaction are simultaneous and at equal rate (1) (1)

(b) Use the data in the table to calculate the standard molar entropy change of the system, $\Delta S^\ominus_{system}$, for this reaction at 298 K. (2)

| Compound | Standard molar entropy, $S^\ominus$ / $J.K^{-1}.mol^{-1}$ |
|---|---|
| $SO_2(g)$ | 248.2 |
| $O_2(g)$ | 205.1 |
| $SO_3(g)$ | 256.8 |

$\Delta S^\ominus_{sys} = 256.8 - \left(248.2 + \frac{205.1}{2}\right)$ (1)

$\Delta S^\ominus_{sys} = -93.95\ J.mol^{-1}.K^{-1}$ or $-94\ J.mol^{-1}.K^{-1}$ (1)

(c) Calculate the total molar entropy change, $\Delta S^{\ominus}_{Total}$, at 298K.
Include a unit and a sign in your answer.

(4)

$$\Delta S^{\ominus}_{surr} = -\frac{\Delta H \times 10^3}{T} = -\frac{-99.0 \times 10^3}{298} = +332.2 \ J.mol^{-1}.K^{-1}$$ (1)

$$\Delta S^{\ominus}_{T} = -93.95 + 332.2$$ (1)

$$\Delta S^{\ominus}_{T} = +238.25 \ J.mol^{-1}.K^{-1}$$ (1)

(d) Deduce the value of $K$ at 298K.

(1)

$$\Delta S_T = R \ln k$$

$$\Rightarrow k = e^{\frac{\Delta S_T}{R}}$$

$$\Rightarrow k = e^{\frac{238.25}{8.31}} = 2.83 \times 10^{12}$$ (1)

*(e) On industrial scale, the production of $SO_3(g)$, using the quoted equilibrium, requires a temperature of 450°C, pressure of 2atm and vanadium(V) oxide as a catalyst.
Comment on the bold type statement mentioned at the start of this exercise.
In your answer you should refer to the following:

- The extent of reaction
- The effect, if any, on the value of $K$ when the catalyst is changed from platinum metal to vanadium(V) oxide.
- The conditions used.

(6)

The production of $SO_3(g)$, using the above equilibrium, has large constant values both at 25°C and 450°C inferring that it's thermodynamically feasible at these 2 temperatures. These high values of K (1)

indicate the equilibrium is already tilted to (1)
the right. Therefore the use of high pressure,
which is expected to be used, has tiny effect
on the yield (1). Hence a pressure of 2 atm
is used on industrial scale.
Catalysts are kinetic factors and have no
effect on the feasibility of a reaction, hence K
won't be affected by the nature of the
catalyst (1)
As for exothermic reactions, $\Delta S_T$ becomes
less positive at high temperature due to
$\Delta S_{surr} = -\frac{\Delta H \times 10^3}{T}$ decreasing, which
(1)
contradicts the use of 450°C on industrial
scale.
Thus, it can only be deduced that this
exothermic process has a high $E_a$ inferring (1)
that the mixture of $SO_2(g)$ and $O_2(g)$ is
kinetically stable

**(Total for Question 25 = 15 marks)**
**TOTAL FOR SECTION C = 15 MARKS**
**TOTAL FOR PAPER = 90 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<br>atomic symbol<br>name<br>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

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Lanthanide series | 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 |
| * Actinide series | 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 |