Diploma Programme
Programme du diplôme
Programa del Diploma

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Chemistry
Higher level
Paper 2

Wednesday 18 May 2022 (afternoon)

Candidate session number

2 hours 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

2222 – 6108

Answer **all** questions. Answers must be written within the answer boxes provided.

1. When heated in air, magnesium ribbon reacts with oxygen to form magnesium oxide.

(a) (i) Write a balanced equation for the reaction that occurs. [1]

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(ii) Identify a metal, in the same period as magnesium, that does **not** form a basic oxide. [1]

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(b) The reaction in (a)(i) was carried out in a crucible with a lid and the following data was recorded:

Mass of crucible and lid = 47.372 ± 0.001 g

Mass of crucible, lid and magnesium ribbon before heating = 53.726 ± 0.001 g

Mass of crucible, lid and product after heating = 56.941 ± 0.001 g

(i) Calculate the amount of magnesium, in mol, that was used. [1]

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(ii) Determine the percentage uncertainty of the mass of product after heating. [2]

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(This question continues on the following page)

(Question 1 continued)

(iii) Assume the reaction in (a)(i) is the only one occurring and it goes to completion, but some product has been lost from the crucible. Deduce the percentage yield of magnesium oxide in the crucible. [2]

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(c) When magnesium is burnt in air, some of it reacts with nitrogen to form magnesium nitride according to the equation:

$$3\,Mg(s) + N_2(g) \rightarrow Mg_3N_2(s)$$

(i) Evaluate whether this, rather than the loss of product, could explain the yield found in (b)(iii). [1]

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(ii) Suggest an explanation, other than product being lost from the crucible or reacting with nitrogen, that could explain the yield found in (b)(iii). [1]

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(This question continues on the following page)

(Question 1 continued)

(d) The presence of magnesium nitride can be demonstrated by adding water to the product. It is hydrolysed to form magnesium hydroxide and ammonia.

(i) Calculate coefficients that balance the equation for the following reaction. [1]

$$\_\_\ Mg_3N_2(s) + \_\_\ H_2O(l) \rightarrow \_\_\ Mg(OH)_2(s) + \_\_\ NH_3(aq)$$

(ii) Ammonia is added to water that contains a few drops of an indicator. Identify an indicator that would change colour. Use sections 21 and 22 of the data booklet. [1]

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(iii) Determine the oxidation state of nitrogen in Mg_3N_2 and in NH_3. [1]

Mg_3N_2: . . . .

NH_3: . . . .

(iv) Deduce, giving reasons, whether the reaction of magnesium nitride with water is an acid–base reaction, a redox reaction, neither or both. [2]

Acid–base: ☐ Yes ☐ No

Reason: . . . .

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Redox: ☐ Yes ☐ No

Reason: . . . .

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(This question continues on the following page)

(Question 1 continued)

(e) Most nitride ions are $^{14}N^{3-}$.

(i) State the number of subatomic particles in this ion. [1]

Protons: . . . .

Neutrons: . . . .

Electrons: . . . .

(ii) Some nitride ions are $^{15}N^{3-}$. State the term that describes the relationship between $^{14}N^{3-}$ and $^{15}N^{3-}$. [1]

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(iii) The nitride ion and the magnesium ion are isoelectronic (they have the same electron configuration). Determine, giving a reason, which has the greater ionic radius. [1]

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(iv) Suggest, giving a reason, whether magnesium or nitrogen would have the greater sixth ionization energy. [1]

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(This question continues on the following page)

(Question 1 continued)

(f) Suggest **two** reasons why atoms are no longer regarded as the indivisible units of matter. [2]

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(g) State the types of bonding in magnesium, oxygen and magnesium oxide, and how the valence electrons produce these types of bonding. [4]

Substance	Bond type	How the valence electrons produce these bonds
Magnesium	. . . .	. . . .
Oxygen	. . . .	. . . .
Magnesium oxide	. . . .	. . . .

2. Magnesium is a reactive metal often found in alloys.

(a) Suggest an experiment that shows that magnesium is more reactive than zinc, giving the observation that would confirm this. [2]

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(b) Magnesium is sometimes used as a sacrificial anode to protect steel from corrosion.

(i) Calculate the standard potential, in V, of a cell formed by magnesium and steel half-cells. Use section 24 of the data booklet and assume steel has the standard electrode potential of iron. [1]

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(ii) Calculate the free energy change, $\Delta G^{\ominus}$, in kJ, of the cell reaction. Use sections 1 and 2 of the data booklet. [2]

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(iii) This cell causes the electrolytic reduction of water on the steel. State the half-equation for this reduction. [1]

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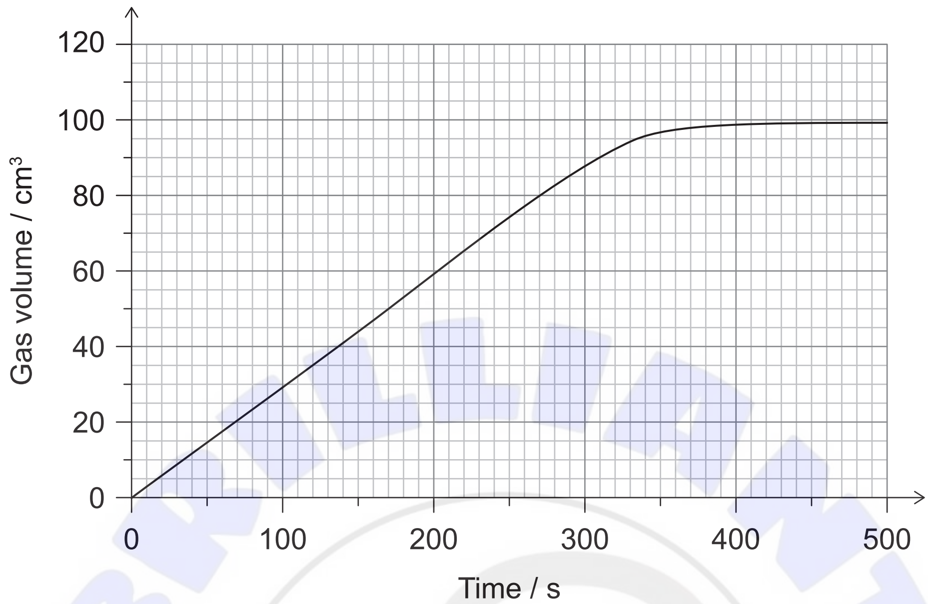
(Question 2 continued)

(c) A graph of the volume of gas produced by reacting magnesium with a large excess of 1 mol dm^{-3} hydrochloric acid is shown.



(i) Use the graph to deduce the dependence of the reaction rate on the amount of Mg. [1]

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(ii) The reaction is first order with respect to HCl. Calculate the time taken, in seconds (s), for half of the Mg to dissolve when $[HCl] = 0.5\,mol\,dm^{-3}$. [1]

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(iii) Carbonates also react with HCl and the rate can be determined by graphing the mass loss. Suggest why this method is less suitable for the reaction of Mg with HCl. [1]

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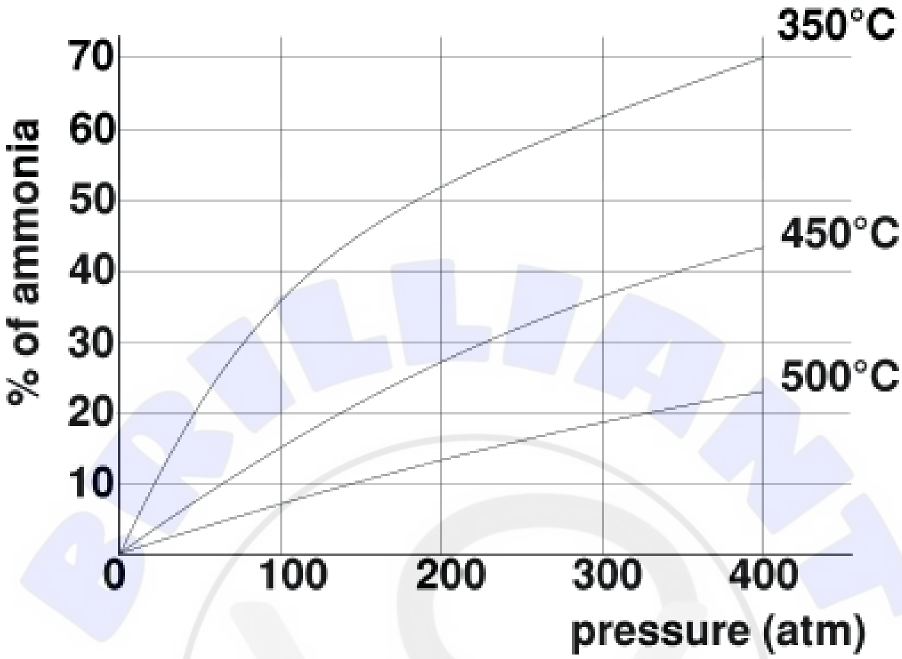
3. Ammonia is produced by the Haber–Bosch process which involves the equilibrium:

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

The percentage of ammonia at equilibrium under various conditions is shown:



(a) (i) Deduce the expression for the equilibrium constant, K_c, for this equation. [1]

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(ii) State how the use of a catalyst affects the position of the equilibrium. [1]

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will not be marked.

(Question 3 continued)

(iii) With reference to the reaction quotient, Q, explain why the percentage yield increases as the pressure is increased at constant temperature. [3]

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(This question continues on the following page)

(Question 3 continued)

(b) One factor affecting the position of equilibrium is the enthalpy change of the reaction.

(i) Determine the enthalpy change, ΔH, for the Haber–Bosch process, in kJ. Use Section 11 of the data booklet. [3]

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(ii) Outline why the value obtained in (b)(i) might differ from a value calculated using ΔH_f data. [1]

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(iii) Demonstrate that your answer to (b)(i) is consistent with the effect of an increase in temperature on the percentage yield, as shown in the graph. [2]

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(This question continues on the following page)

(Question 3 continued)

(c) The standard free energy change, $\Delta G^{\ominus}$, for the Haber–Bosch process is –33.0 kJ at 298 K.

(i) State, giving a reason, whether the reaction is spontaneous or not at 298 K. [1]

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(ii) Calculate the value of the equilibrium constant, *K*, at 298 K. Use sections 1 and 2 of the data booklet. [2]

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(iii) Calculate the entropy change for the Haber–Bosch process, in $J\,mol^{-1}\,K^{-1}$ at 298 K. Use your answer to (b)(i) and section 1 of the data booklet. [2]

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(iv) Outline, with reference to the reaction equation, why this sign for the entropy change is expected. [1]

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4. Ammonia is soluble in water and forms an alkaline solution:

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + HO^-(aq)$$

(a) State the relationship between NH_4^+ and NH_3 in terms of the Brønsted–Lowry theory. [1]

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(b) Determine the concentration, in mol dm^{-3}, of the solution formed when 900.0 dm^3 of NH_3(g) at 300.0 K and 100.0 kPa, is dissolved in water to form 2.00 dm^3 of solution. Use sections 1 and 2 of the data booklet. [2]

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(c) (i) Calculate the concentration of hydroxide ions in an ammonia solution with pH = 9.3. Use sections 1 and 2 of the data booklet. [1]

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(ii) Calculate the concentration, in mol dm^{-3}, of ammonia molecules in the solution with pH = 9.3. Use section 21 of the data booklet. [2]

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(Question 4 continued)

(iii) An aqueous solution containing high concentrations of both NH_3 and NH_4^+ acts as an acid-base buffer solution as a result of the equilibrium:

$$NH_3(aq) + H^+(aq) \rightleftharpoons NH_4^+(aq)$$

Referring to this equilibrium, outline why adding a small volume of strong acid would leave the pH of the buffer solution almost unchanged. [2]

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(d) Magnesium salts form slightly acidic solutions owing to equilibria such as:

$$Mg^{2+}(aq) + H_2O(l) \rightleftharpoons Mg(OH)^+(aq) + H^+(aq)$$

Comment on the role of Mg^{2+} in forming the $Mg(OH)^+$ ion, in acid-base terms. [2]

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(This question continues on the following page)

(Question 4 continued)

(e) $Mg(OH)^+$ is a complex ion, but Mg is not regarded as a transition metal. Contrast Mg with manganese, Mn, in terms of one characteristic chemical property of transition metals, other than complex ion formation. [2]

Property: . . . .

Comparison: . . . .

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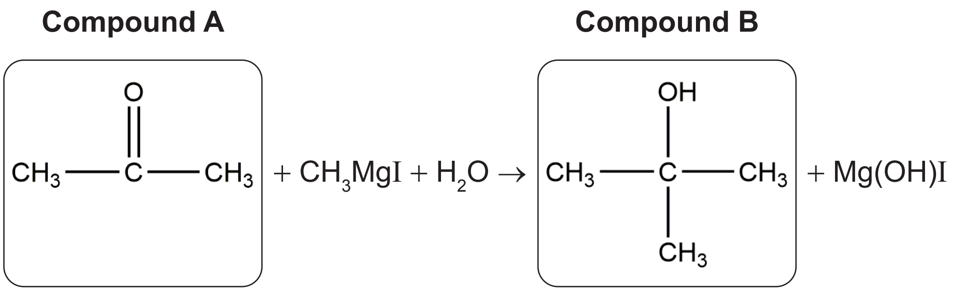
5. Organomagnesium compounds can react with carbonyl compounds. One overall equation is:



(a) (i) State the name of Compound B, applying International Union of Pure and Applied Chemistry (IUPAC) rules. [1]

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(ii) Compound A and Compound B are both liquids at room temperature and pressure. Identify the strongest intermolecular force between molecules of Compound A. [1]

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(iii) State the number of σ (sigma) and π (pi) bonds in Compound A. [1]

σ: . . . . π: . . . .

(iv) Deduce the hybridization of the central carbon atom in Compound A. [1]

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(v) Identify the isomer of Compound B that exists as optical isomers (enantiomers). [1]

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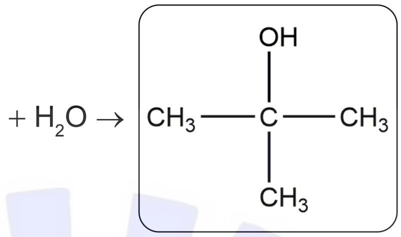
(Question 5 continued)

(b) Compound B can also be prepared by reacting an alkene with water.

(i) Draw the structural formula of the alkene required. [1]

Compound B



(ii) Explain why the reaction produces more $(CH_3)_3COH$ than $(CH_3)_2CHCH_2OH$. [2]

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(iii) Deduce the structural formula of the repeating unit of the polymer formed from this alkene. [1]

(This question continues on the following page)

(Question 5 continued)

(c) Deduce what would be observed when Compound B is warmed with acidified aqueous potassium dichromate (VI). [1]

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(d) Iodomethane is used to prepare CH_3MgI. It can also be converted into methanol:

$$CH_3I + HO^- \rightarrow CH_3OH + I^-$$

(i) Identify the type of reaction. [1]

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(ii) Outline the requirements for a collision between reactants to yield products. [2]

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will not be marked.

(Question 5 continued)

(iii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs. [3]

(iv) The polarity of the carbon–halogen bond, C–X, facilitates attack by HO^-.
Outline, giving a reason, how the bond polarity changes going down group 17. [1]

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6. Nitric acid is usually produced by the oxidation of ammonia.

(a) (i) Draw arrows in the boxes to represent the electron configuration of a nitrogen atom. [1]

2p ☐ ☐ ☐

2s ☐

1s ☐

(ii) Deduce a Lewis (electron dot) structure of the nitric acid molecule, HNO_3, that obeys the octet rule, showing any non-zero formal charges on the atoms. [2]

(iii) Explain the relative lengths of the three bonds between N and O in nitric acid. [3]

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(This question continues on the following page)

(Question 6 continued)

(iv) State a technique used to determine the length of the bonds between N and O in solid HNO_3. [1]

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(b) A mixture of nitric acid and sulfuric acid can be used to convert benzene to nitrobenzene, $C_6H_5NO_2$.

(i) Write an equation for the reaction between the acids to produce the electrophile, NO_2^+. [1]

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(ii) Draw the structural formula of the carbocation intermediate produced when this electrophile attacks benzene. [1]

(iii) Deduce the number of signals that you would expect in the ^1H NMR spectrum of nitrobenzene and the relative areas of these. [2]

Number of signals: . . . .

Relative areas: . . . .

References:

3. The Haber Bosch Process [graph] Available at: https://commons.wikimedia.org/wiki/File:Ammonia_yield.png [Accessed: 16/07/2022].