Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Wednesday 16 May 2018 (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 **[95 marks]**.

2218 – 6108

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

1. Urea, $(H_2N)_2CO$, is excreted by mammals and can be used as a fertilizer.

(a) (i) Calculate the percentage by mass of nitrogen in urea to two decimal places using section 6 of the data booklet. [2]

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(ii) Suggest how the percentage of nitrogen affects the cost of transport of fertilizers giving a reason. [1]

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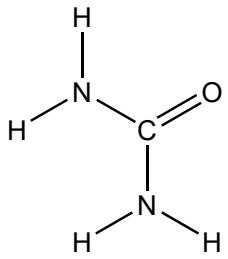
(Question 1 continued)

(b) The structural formula of urea is shown.



Predict the electron domain and molecular geometries at the nitrogen and carbon atoms, applying the VSEPR theory.

	Electron domain geometry	Molecular geometry
Nitrogen	. . . . .	. . . . .
Carbon	. . . . .	trigonal planar

[3]

(c) Urea can be made by reacting potassium cyanate, KNCO, with ammonium chloride, NH_4Cl.

$$KNCO\,(aq) + NH_4Cl\,(aq) \rightarrow (H_2N)_2CO\,(aq) + KCl\,(aq)$$

Determine the maximum mass of urea that could be formed from 50.0 cm^3 of 0.100 mol dm^{-3} potassium cyanate solution. [2]

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(Question 1 continued)

(d) Urea can also be made by the direct combination of ammonia and carbon dioxide gases.

$$2NH_3(g) + CO_2(g) \rightleftharpoons (H_2N)_2CO(g) + H_2O(g) \qquad \Delta H < 0$$

(i) State the equilibrium constant expression, K_c. [1]

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(ii) Predict, with a reason, the effect on the equilibrium constant, K_c, when the temperature is increased. [1]

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(iii) Determine an approximate order of magnitude for K_c, using sections 1 and 2 of the data booklet. Assume $\Delta G^{\ominus}$ for the forward reaction is approximately +50 kJ at 298 K. [2]

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(e) (i) Suggest one reason why urea is a solid and ammonia a gas at room temperature. [1]

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(This question continues on the following page)

(Question 1 continued)

(ii) Sketch two different hydrogen bonding interactions between ammonia and water. [2]

(f) The combustion of urea produces water, carbon dioxide and nitrogen.

Formulate a balanced equation for the reaction. [2]

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(g) Calculate the maximum volume of CO_2, in cm^3, produced at STP by the combustion of 0.600 g of urea, using sections 2 and 6 of the data booklet. [1]

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(Question 1 continued)

(h) Describe the bond formation when urea acts as a ligand in a transition metal complex ion. [2]

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(i) The C–N bonds in urea are shorter than might be expected for a single C–N bond. Suggest, in terms of electrons, how this could occur. [1]

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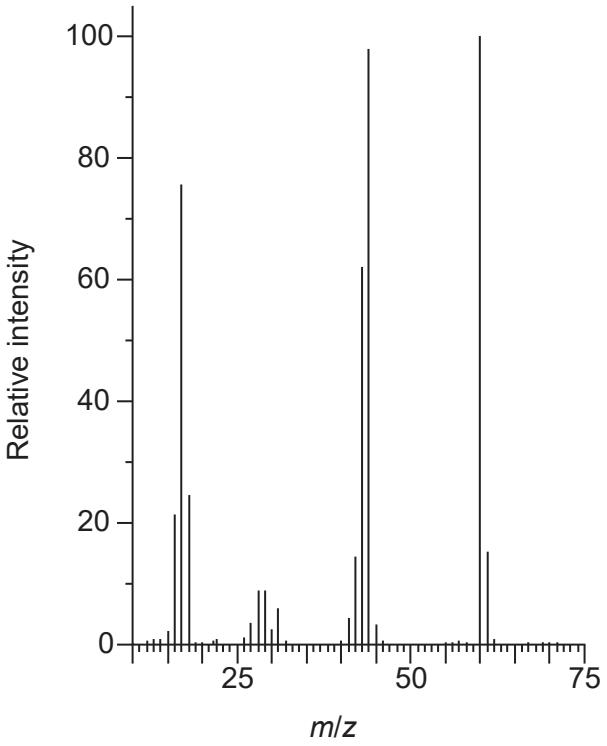
(Question 1 continued)

(j) The mass spectrum of urea is shown below.



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in *NIST Chemistry WebBook*, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, doi:10.18434/T4D303, (retrieved May 31, 2018).]

Identify the species responsible for the peaks at *m*/*z* = 60 and 44. [2]

60:

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44:

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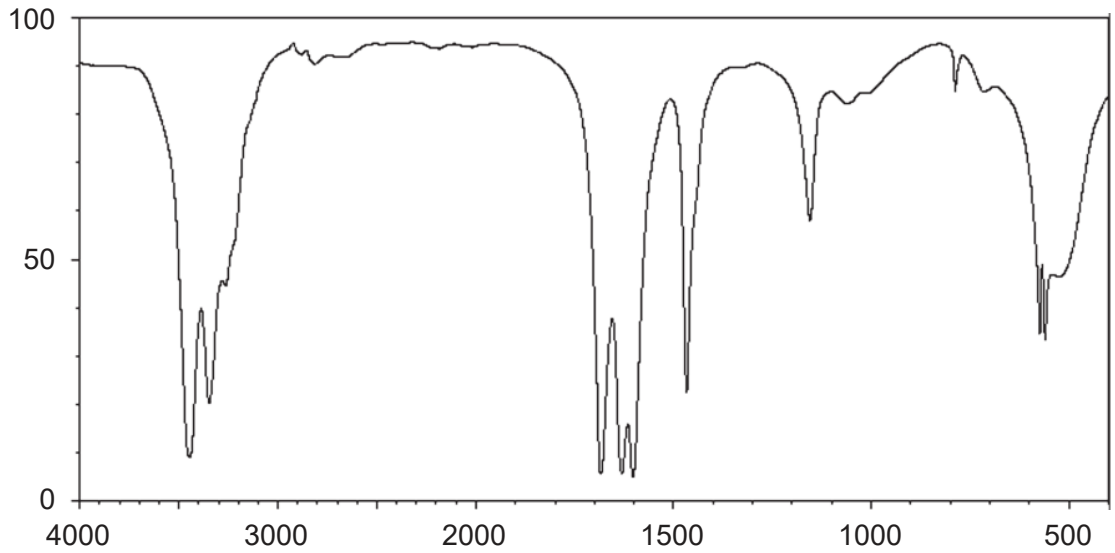
(This question continues on the following page)

(Question 1 continued)

(k) The IR spectrum of urea is shown below.



[Source: SDBS, National Institute of Advanced Industrial Science and Technology]

Identify the bonds causing the absorptions at 3450 cm^{-1} and 1700 cm^{-1} using section 26 of the data booklet. [2]

3450 cm^{-1}:

. . . . . .

1700 cm^{-1}:

. . . . . .

(This question continues on the following page)

(Question 1 continued)

(l) (i) Predict the number of signals in the ^{1}H NMR spectrum of urea. [1]

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(ii) Predict the splitting pattern of the ^{1}H NMR spectrum of urea. [1]

. . . . . .

(iii) Outline why TMS (tetramethylsilane) may be added to the sample to carry out ^{1}H NMR spectroscopy and why it is particularly suited to this role. [2]

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2. Calcium carbide, CaC_2, is an ionic solid.

(a) Describe the nature of ionic bonding. [1]

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(b) Describe how the relative atomic mass of a sample of calcium could be determined from its mass spectrum. [2]

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(This question continues on the following page)

(Question 2 continued)

(c) When calcium compounds are introduced into a gas flame a red colour is seen; sodium compounds give a yellow flame. Outline the source of the colours and why they are different. [2]

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(d) (i) Suggest **two** reasons why solid calcium has a greater density than solid potassium. [2]

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(ii) Outline why solid calcium is a good conductor of electricity. [1]

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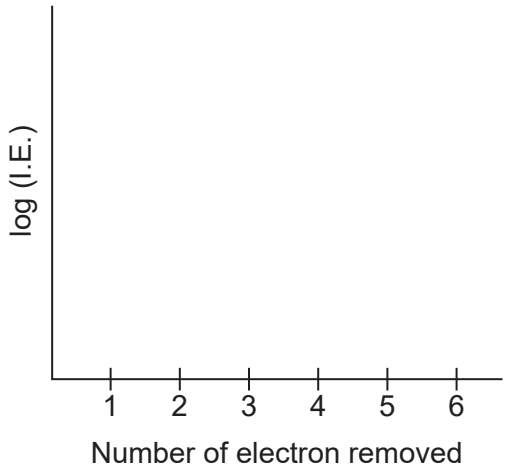
(Question 2 continued)

(e) Sketch a graph of the first six ionization energies of calcium. [2]



(f) Calcium carbide reacts with water to form ethyne and calcium hydroxide.

$$CaC_2(s) + H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

Estimate the pH of the resultant solution. [1]

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(g) (i) Describe how sigma (σ) and pi (π) bonds are formed. [2]

sigma (σ):

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pi (π):

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(This question continues on the following page)

(Question 2 continued)

(ii) Deduce the number of σ and π bonds in a molecule of ethyne. [1]

sigma (σ):

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pi (π):

. . . . . .

3. This question is about ethene, C_2H_4, and ethyne, C_2H_2.

(a) (i) Ethyne, like ethene, undergoes hydrogenation to form ethane. State the conditions required. [2]

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(ii) Outline the formation of polyethene from ethene by drawing three repeating units of the polymer. [1]

(This question continues on the following page)

(Question 3 continued)

(b) Ethyne reacts with chlorine in a similar way to ethene. Formulate equations for the following reactions. [2]

One mole of ethyne reacts with one mole of chlorine:

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One mole of benzene reacts with one mole of chlorine:

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(c) (i) Under certain conditions, ethyne can be converted to benzene.

Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the reaction stated, using section 11 of the data booklet. [2]

$$3C_2H_2(g) \rightarrow C_6H_6(g)$$

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(This question continues on the following page)

(Question 3 continued)

(ii) Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the following similar reaction, using ΔH_f values in section 12 of the data booklet. [2]

$$3C_2H_2(g) \rightarrow C_6H_6(l)$$

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(iii) Explain, giving two reasons, the difference in the values for (c)(i) and (ii). If you did not obtain answers, use –475 kJ for (i) and –600 kJ for (ii). [2]

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(iv) Calculate the standard entropy change, $\Delta S^{\ominus}$, in J K^{-1}, for the reaction in (ii) using section 12 of the data booklet. [1]

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(Question 3 continued)

(v) Determine, showing your working, the spontaneity of the reaction in (ii) at 25 °C. [3]

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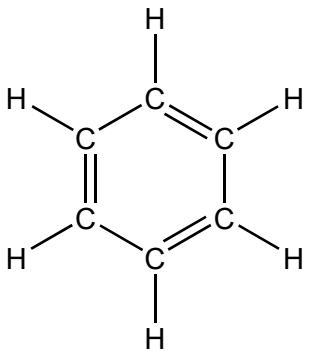
(d) One possible Lewis structure for benzene is shown.



State one piece of physical evidence that this structure is **incorrect**. [1]

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4. Calcium carbonate reacts with hydrochloric acid.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

(a) Outline **two** ways in which the progress of the reaction can be monitored. No practical details are required. [2]

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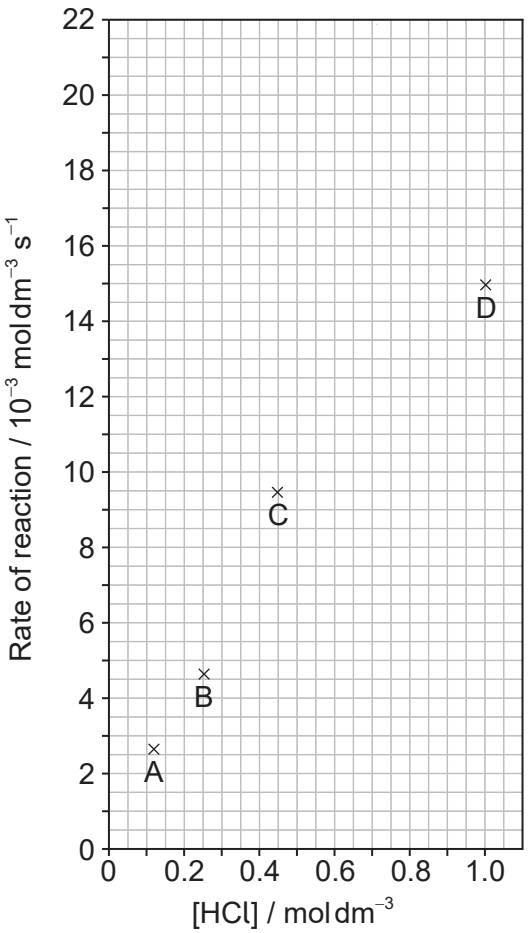
(b) The results of a series of experiments in which the concentration of HCl was varied are shown below.



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(Question 4 continued)

(i) Suggest why point D is so far out of line assuming human error is not the cause. [1]

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(ii) Draw the best fit line for the reaction excluding point D. [1]

(iii) Suggest the relationship that points A, B and C show between the concentration of the acid and the rate of reaction. [1]

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(iv) Deduce the rate expression for the reaction. [1]

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(v) Calculate the rate constant of the reaction, stating its units. [2]

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(c) Predict from your line of best fit the rate of reaction when the concentration of HCl is 1.00 mol dm^{-3}. [1]

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(This question continues on the following page)

(Question 4 continued)

(d) Describe how the activation energy of this reaction could be determined. [3]

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5. Limescale, $CaCO_3$ (s), can be removed from water kettles by using vinegar, a dilute solution of ethanoic acid, CH_3COOH (aq).

(a) Predict, giving a reason, a difference between the reactions of the same concentrations of hydrochloric acid and ethanoic acid with samples of calcium carbonate. [2]

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(b) Dissolved carbon dioxide causes unpolluted rain to have a pH of approximately 5, but other dissolved gases can result in a much lower pH. State one environmental effect of acid rain. [1]

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(Question 5 continued)

(c) Write an equation to show ammonia, NH_3, acting as a Brønsted–Lowry base and a different equation to show it acting as a Lewis base. [2]

Brønsted–Lowry base:

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. . . . . .

Lewis base:

. . . . . .

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(d) Determine the pH of 0.010 mol dm^{-3} 2,2-dimethylpropanoic acid solution.

K_a (2,2-dimethylpropanoic acid) $= 9.333 \times 10^{-6}$ [2]

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(e) Explain, using appropriate equations, how a suitably concentrated solution formed by the partial neutralization of 2,2-dimethylpropanoic acid with sodium hydroxide acts as a buffer solution. [2]

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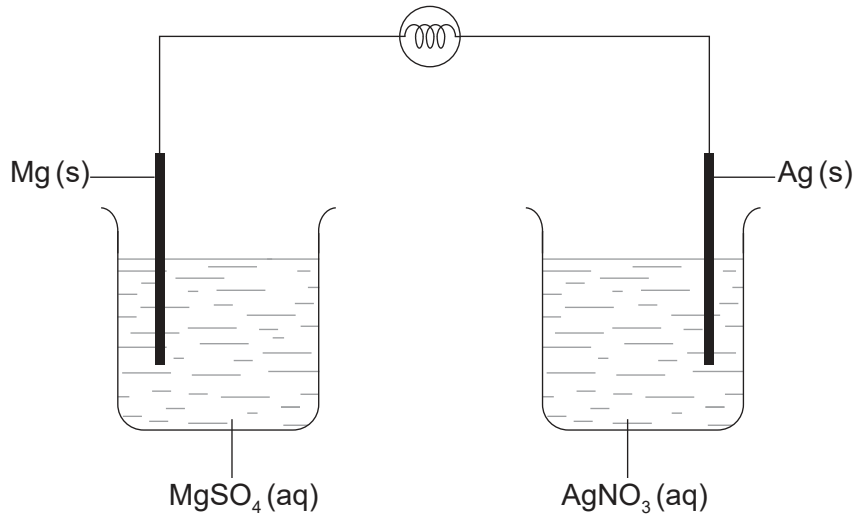
6. The diagram shows an incomplete voltaic cell with a light bulb in the circuit.



(a) Identify the missing component of the cell and its function. [2]

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(b) Deduce the half-equations for the reaction at each electrode when current flows. [2]

Positive electrode (cathode):

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Negative electrode (anode):

. . . . . .

(c) Annotate the diagram with the location and direction of electron movement when current flows. [1]

(d) Calculate the cell potential, in V, using section 24 of the data booklet. [1]

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(This question continues on the following page)

(Question 6 continued)

(e) Determine the loss in mass of one electrode if the mass of the other electrode increases by 0.10 g. [2]

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7. This question is about the reactions of halogenoalkanes.

(a) Compare and contrast the mechanisms by which 1-chlorobutane, $CH_3CH_2CH_2CH_2Cl$, and 2-chloro-2-methylpropane, $(CH_3)_3CCl$, react with aqueous sodium hydroxide, giving **two** similarities and **one** difference. [3]

Two similarities:

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One difference:

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(b) Outline why the rate of reaction of the similar bromo-compounds is faster. [1]

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(This question continues on the following page)

(Question 7 continued)

(c) (i) State the organic product of the reaction between 1-chlorobutane, $CH_3CH_2CH_2CH_2Cl$, and aqueous sodium hydroxide. [1]

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(ii) Suggest how this product could be synthesized in one step from butanoic acid. [1]

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(iii) Deduce the name of the class of compound formed when the product of (c)(i) reacts with butanoic acid. [1]

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