CHEMISTRY
Higher level
Paper 2
Preliminary Examinations

Wednesday 30 August 2023

2 hours 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your name, class and index number in the blanks below.
- 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]**.

Name: _____

Class: _____

Index: _____

90

1. (a) An oxide of chromium contains 68.4% of chromium and 31.6% of oxygen. The mass spectrum of the oxide shows its molecular ion peak at m/z = 156. Determine the molecular formula of the oxide, showing your working. [3]

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(b) (i) When copper compounds are introduced into a gas flame, the flame turns green. Calcium compounds produce a brick red flame while chromium compounds produce a silver-white flame. Explain why different colours are observed in the gas flame. [2]

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(ii) Explain the convergence of lines in an emission spectrum. [1]

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(iii) The frequency of convergence limit for the chromium atom is $1.64 \times 10^{15}\ s^{-1}$. Calculate the ionization energy, in J, for a single atom of chromium using sections 1 and 2 of the data booklet. [1]

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(c) (i) State the **full** electron configuration of the chromium atom. [1]

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(ii) Predict and explain the magnetic properties of chromium atoms and chromium(III) ions. [2]

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(iii) Describe how the bonds between water ligands and chromium(III) ion are formed using Lewis acids and bases. [1]

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(iv) Explain why chromium(III) nitrate solutions are green, using section 17 of the data booklet. [3]

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2. (a) Methane is the main component of natural gas and a common gaseous fuel.

(i) Write the chemical equation for the combustion of methane under standard conditions. [1]

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(ii) Calculate the enthalpy change of combustion of methane, in kJ mol^{-1}, using section 12 of the data booklet. [2]

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(iii) The enthalpy change of combustion of methane calculated using average bond enthalpies is -808 kJ mol^{-1}. Explain the difference between this value and your answer from (a)(ii). [1]

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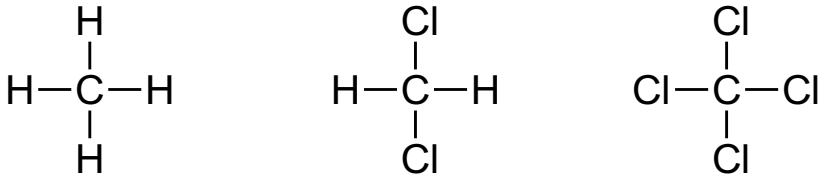
(b) Methane reacts with chlorine, Cl_2, to form a range of substituted chloromethanes. The structural formulae of methane and two chloromethanes are shown below.



Methane Dichloromethane Tetrachloromethane

(i) Discuss the overall polarity of the three molecules. [3]

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(ii) Explain why methane is a gas while tetrachloromethane is a liquid at SATP conditions (298 K, 100 kPa). [1]

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(iii) Outline why methane is insoluble in water. [1]

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(c) At sea level, ozone is commonly formed during the combustion of methane in excess oxygen. The chemical equation for the formation of ozone is shown below.

$$3O_2\,(g) \rightarrow 2O_3\,(g) \qquad \Delta H^{\ominus} = +\,285.4\ kJ$$

(i) Calculate the average bond enthalpy, in kJ, of the oxygen-oxygen bond in ozone using section 11 of the data booklet. [2]

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(ii) Draw the Lewis structure of an ozone molecule. Label the formal charge of each oxygen atom in the ozone molecule. [2]

(iii) Using your answer to (c)(i) and section 11 of the data booklet, comment on the bond order and bond length of the oxygen-oxygen bond in ozone. [2]

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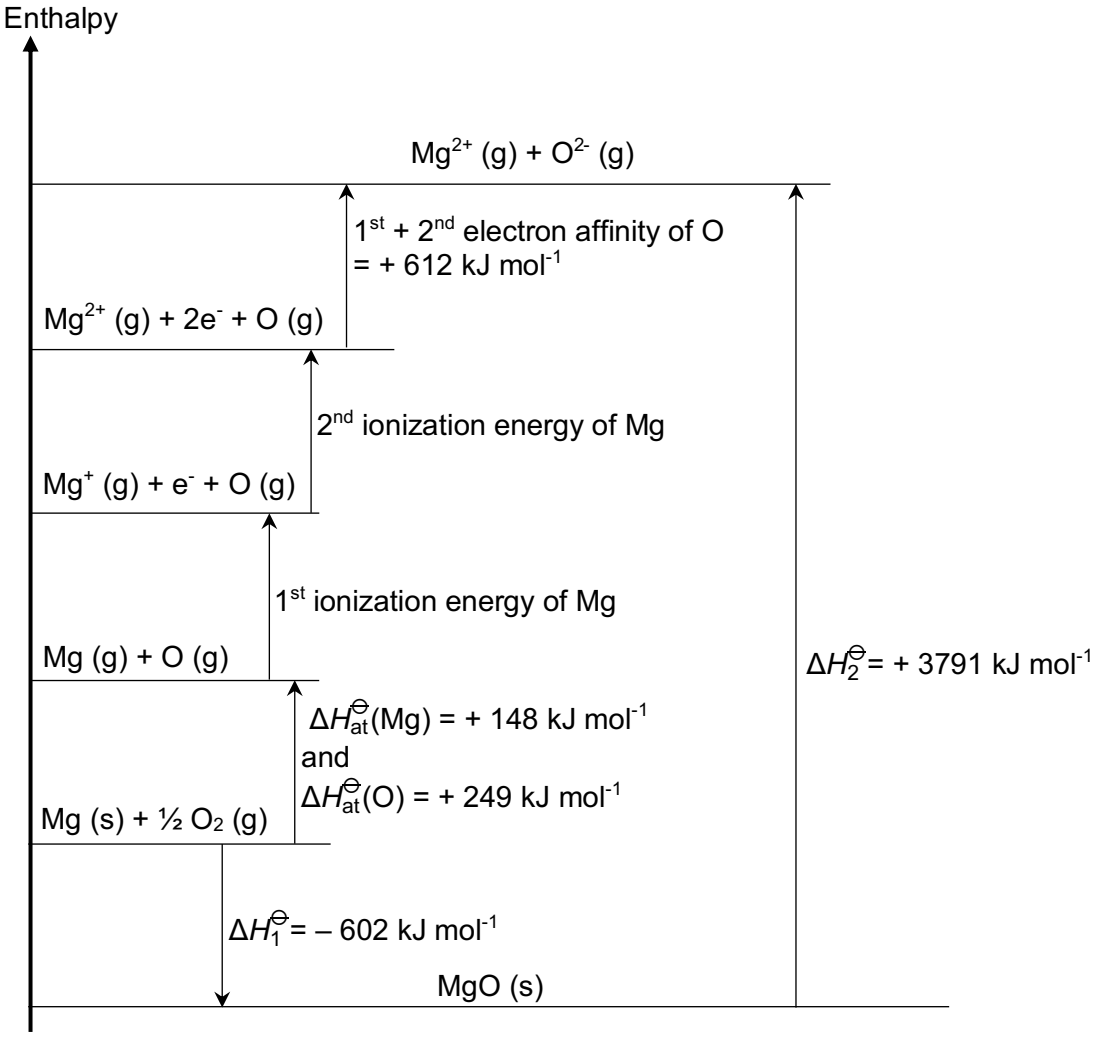
(d) The Born-Haber cycle of magnesium oxide is shown below.



(i) State the processes for $\Delta H_1^{\ominus}$ and $\Delta H_2^{\ominus}$. [2]

$\Delta H_1^{\ominus}$: ……

$\Delta H_2^{\ominus}$: ……

(ii) Using section 8 of the data booklet, calculate the enthalpy change of the 2nd ionization energy of magnesium. [2]

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(iii) Comment on the difference in the values of 1st and 2nd ionization energy of magnesium. If you did not get the value in (ii), you may assume the 2nd ionization energy of magnesium to be + 1000 kJ mol^{-1}. However this may not be the correct answer. [1]

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(iv) Using section 18 of the data booklet, state and explain the trend in the lattice enthalpy values of the group 2 oxides. [2]

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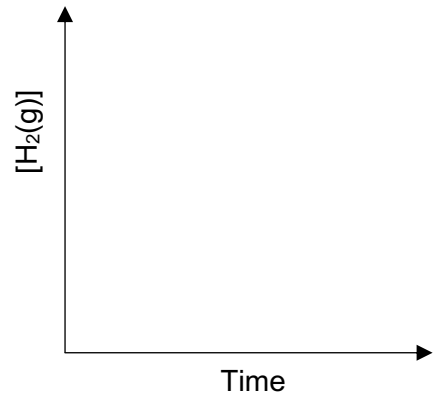
3. The following gaseous reaction is taking place in a sealed vessel.

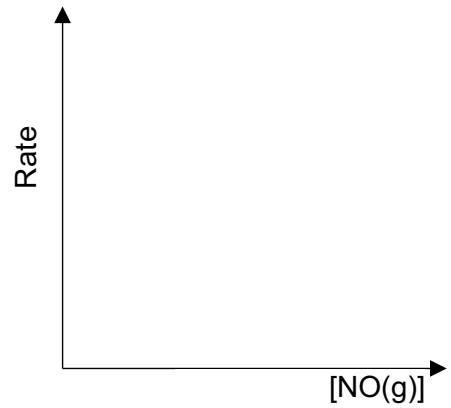
$$2H_2(g) + 2NO(g) \rightarrow 2H_2O(g) + N_2(g)$$

The rate expression for this reaction is rate = $k[NO]^2$.

(a) (i) Sketch a graph of concentration of $H_2(g)$ against time. [1]



(ii) Sketch a graph of rate against concentration of NO(g). [1]



(b) Suggest, with a reason, how the rate of reaction changes when the volume of the vessel is halved at constant temperature. [2]

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(c) Deduce the units of the rate constant for the reaction. [1]

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(d) Explain why the rate of a gaseous reaction increases with increasing temperature. [3]

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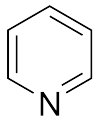
4. Pyridine, C_5H_5N, is a weak *Brønsted* base and its base dissociation constant (K_b) is 1.4×10^{-9}. Aqueous pyridine reacts with hydrochloric acid to form a salt solution containing pyridinium chloride. (1 mole of pyridine reacts with 1 mole of hydrochloric acid.)



pyridine

(a) (i) Formulate an equation for the reaction between aqueous pyridine and hydrochloric acid. [1]

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(ii) State, with a reason, whether the pyridinium ion formed is a Brønsted-Lowry acid or base. [1]

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(b) A 0.100 mol dm^{-3} solution of pyridinium chloride is prepared.

(i) 25.00 cm^3 of the pyridinium chloride solution is titrated with a 0.100 mol dm^{-3} solution of sodium hydroxide. Calculate the pH at the equivalence point, leaving your answer to **two** decimal places. [4]

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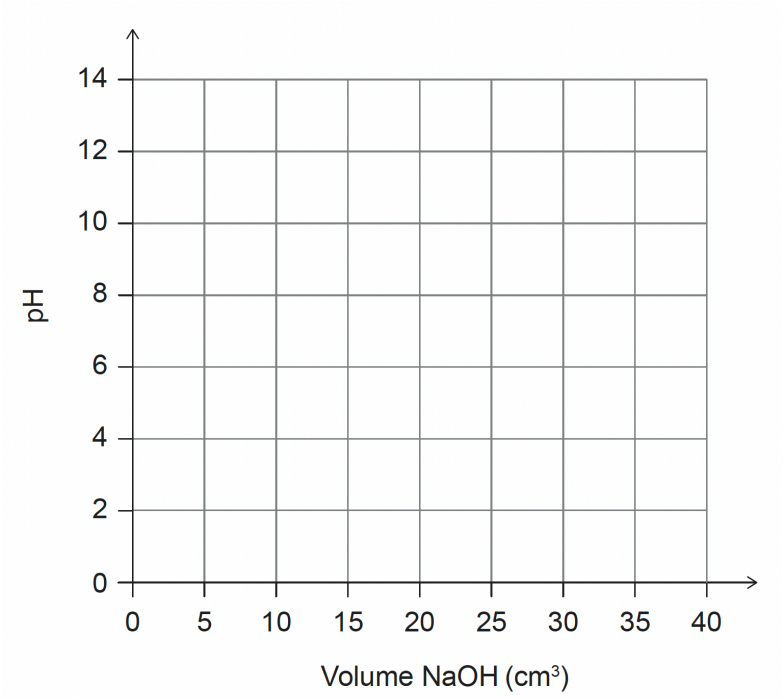
(ii) Sketch the pH curve that would result from the titration of 0.100 mol dm^{-3} solution of pyridinium chloride with 0.100 mol dm^{-3} solution of sodium hydroxide. [2]



(c) Pyridine undergoes hydrogenation to form piperidine. The hydrogenation of pyridine to form piperidine is represented by the following equation.

$$C_5H_5N\,(g) + 3\,H_2\,(g) \rightleftharpoons C_5H_{11}N\,(g)$$

State and explain the effect of the following changes, if any, on the position of equilibrium.

I. Increasing the pressure [2]

II. Adding a catalyst [2]

I. Increasing the pressure:

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II. Adding a catalyst:

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(d) The equilibrium constant, K_c, for the hydrogenation of pyridine to piperidine is found to be 3.80×10^{-16} at 500 K.

(i) Predict, with a reason, the yield of piperidine at 500 K. [1]

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(ii) Calculate the Gibbs free energy change, ΔG, in kJ mol^{-1}, for the hydrogenation of pyridine to piperidine at 500 K. [2]

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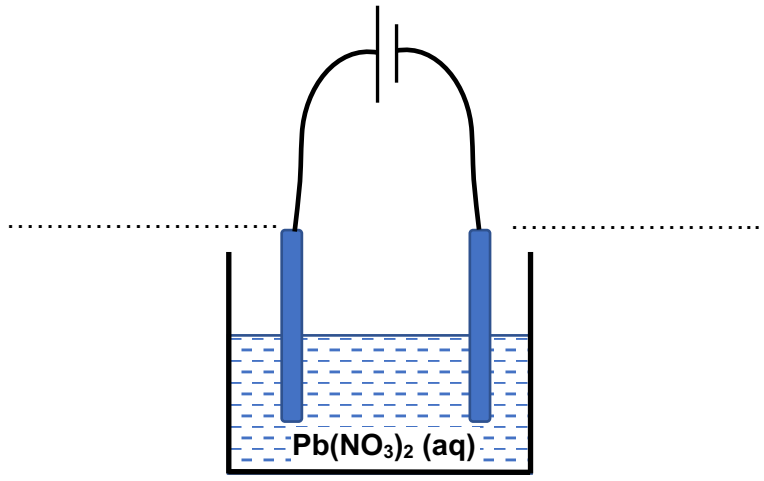
5. An electrolytic cell is made up of graphite rods as the electrodes and aqueous lead(II) nitrate as the electrolyte.



(a) Label the anode and cathode of the cell in the diagram. [1]

(b) Outline how the electric current flows through the circuit. [2]

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(c) A grey metallic solid is formed on the cathode and a colourless gas is formed at the anode.

(i) For each electrode, deduce the half-equation. [2]

Cathode:

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Anode:

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(ii) Deduce the equation of the overall cell reaction. [1]

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(d) Predict and explain the chemical reaction that will happen at the cathode if the electrolyte is changed to manganese(II) nitrate, using section 24 of the data booklet. [2]

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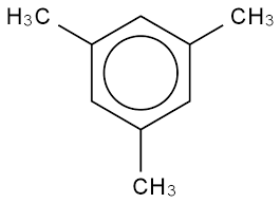
6. Mesitylene (1,3,5-trimethylbenzene) is a derivative of benzene.



(a) State the number of ^{1}H NMR signals for mesitylene and the ratio in which they appear. [2]

Number of signals:

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Ratio:

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(b) Draw the structure of **one** isomer of mesitylene which retains the benzene ring. [1]

(c) Mesitylene, like benzene, can be nitrated.

(i) Write the equation to produce the active nitrating agent for benzene using suitable chemicals. [1]

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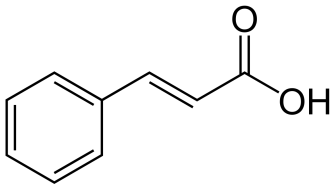
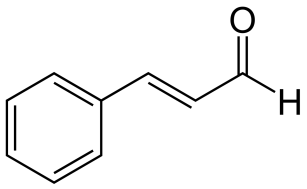
(ii) Explain the mechanism for the nitration of mesitylene, using curly arrows to indicate the movement of electron pairs. [4]

7. (a) Cinnamic acid and cinnamaldehyde are two compounds found in cinnamon.

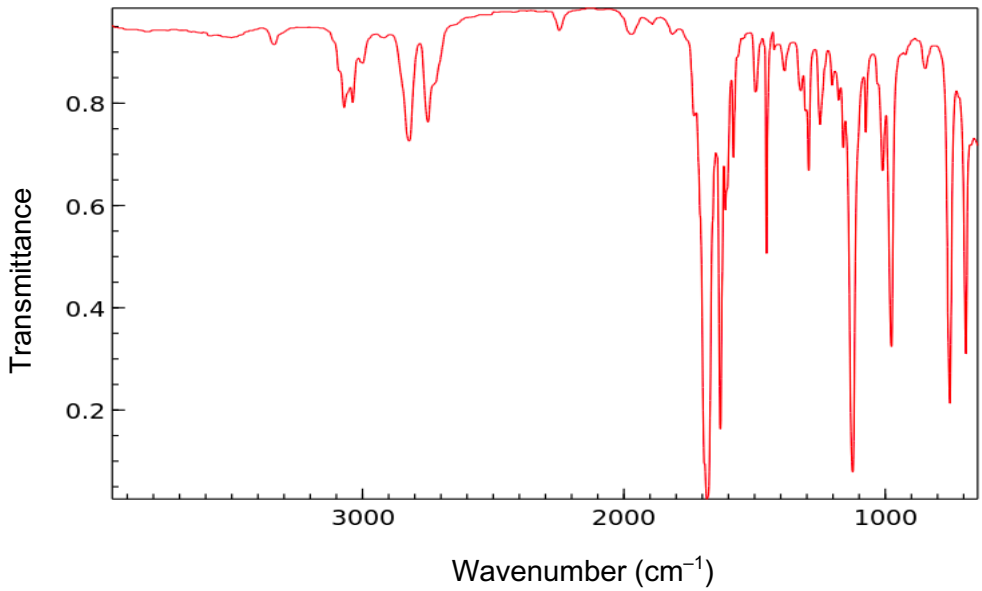


Cinnamic acid



Cinnamaldehyde

(i) The IR spectrum of one of the two compounds is shown:



Source: https://webbook.nist.gov/cgi/cbook.cgi?ID=C104552&Units=SI&Type=IR-SPEC&Index=1

Deduce, giving a reason, the compound producing this spectrum. [1]

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(ii) State, giving a reason, if cinnamic acid exhibits E/Z isomerism. [1]

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(iii) Cinnamic acid can undergo addition polymerization. Draw a section of the resulting polymer showing **two** repeating units. [1]

(iv) Draw the structural formula of the organic compound formed from the reaction between cinnamic acid and methanol. [1]

(v) State the type of reaction that occurs when cinnamic acid reacts with hydrogen iodide. [1]

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(vi) Describe the observation when bromine water is added to a solution of cinnamic acid. [1]

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(vii) Draw the structural formula of the alcohol that can be converted to cinnamic acid. State the reagents and condition required for this conversion. [3]

Reagents: ……

Condition: ……..

(b) Explain how ethanoic acid, M_r = 60.05, forms a dimer, M_r = 120.10 in the vapour state. [1]

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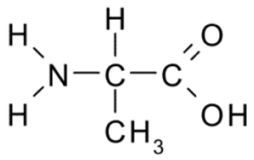
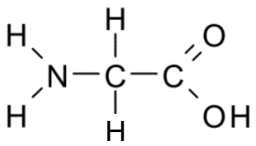
(c) The structures of two organic acids are shown below.



A



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(i) State the molecular geometry around the nitrogen atom and its hybridization in acid **A**. [2]

Molecular geometry: ……..……...…

Hybridization ……..……..…..

(ii) Deduce, giving a reason, which of the two compounds shows optical activity. [1]

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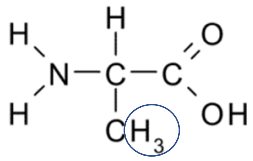
(iii) Draw the wedge and dash (three-dimensional) representations of the two enantiomers using your answer for (c)(ii). [1]

(iv) Predict the splitting pattern of the circled hydrogen atoms in the ^{1}H NMR spectrum of acid **A**.



[1]

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