Anglo-Chinese School
(Independent)

YEAR 6 PRELIMINARY EXAMINATION 2019
INTERNATIONAL BACCALAUREATE DIPLOMA PROGRAMME
CHEMISTRY HIGHER LEVEL

PAPER 2

Wednesday **18th September 2019** **2 hours 15 minutes**

Candidate Session Number

0	0	2	3	2	9				

INSTRUCTIONS TO CANDIDATES

- Do not open this examination paper until instructed to do so.
- Write your **candidate session number in the box above**.
- A calculator is required for this paper.
- A copy of the Chemistry Data Booklet is required for this paper.
- Write your answers in the boxes provided.
- If you use additional sheets of paper for your answer, attach them to the booklet. Indicate the question number clearly on these sheets.

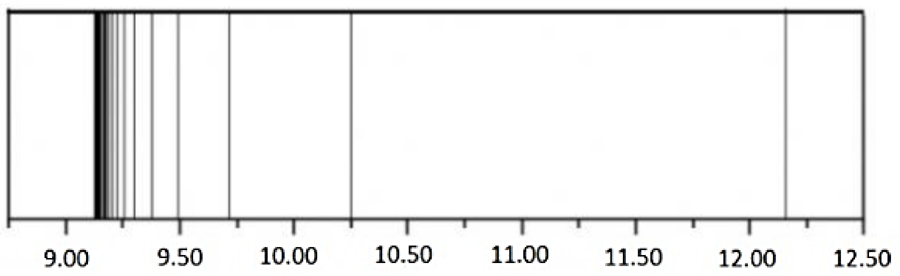
For examiner's use	
Qn 1	/5
Qn 2	/5
Qn 3	/9
Qn 4	/10
Qn 5	/11
Qn 6	/7
Qn 7	/12
Qn 8	/8
Qn 9	/15
Qn 10	/8
Wrong s.f. /units	
Total	/90

This question paper consists of 22 printed pages including this cover page.

Answer **all** questions. Write your answers in the boxes provided.

1. The lines in the ultraviolet emission spectrum of hydrogen gas converge at 9.12×10^{-8} m.

Limit 9.12 9.72 10.26 1st line 12.16



wavelength / $\times 10^{-8}$ m

(a) Calculate the ionization energy of hydrogen in kJ mol^{-1}. [2]

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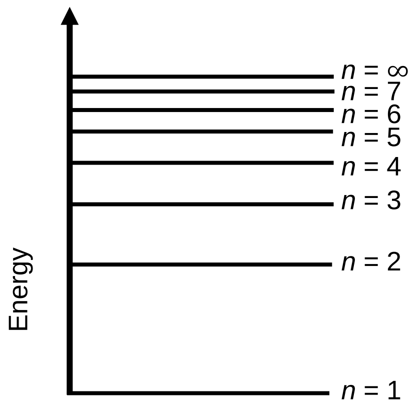
(b) Sketch on the energy-level diagram below showing the transition that corresponds to the convergence limit that leads to the line with the shortest wavelength in the hydrogen emission spectrum. [1]



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(Question 1 continued)

(c) Explain why the convergence limit in the visible spectrum is **not** used to calculate the ionization energy. [2]

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2. Transition metals commonly form coloured complexes. In aqueous solution, nickel(II) sulfate, $NiSO_4$, forms the green hexaaqua nickel(II) complex ion, $[Ni(H_2O)_6]^{2+}(aq)$.

(a) State the type of reaction that takes place between Ni^{2+} and H_2O to form $[Ni(H_2O)_6]^{2+}$. [1]

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(b) Complete the table below to show the coordination numbers of the following transition metal complex ions. [1]

Complex ion	$[Ag(NH_3)_2]^+$	$[CuCl_4]^{2-}$	$[Ni(H_2O)_6]^{2+}$
Coordination number			

(c) Complex ions consist of a central metal ion bonded to ligands. Define the term *ligand*. [1]

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(This question continues on the following page)

(Question 2 continued)

(d) When a solution of 1,2-ethanediamine (en) is added to a solution of aqueous nickel(II) sulfate, the colour of the solution changes from green to dark blue and finally to violet as $[Ni(en)_3]^{2+}$ complex ions are formed. With reference to section 17 of the data booklet, deduce with reason the effect of the 1,2-ethanediamine ligand on the splitting of the d-orbitals. [2]

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3. (a) Hydrazoic acid, N_3H, is an explosive liquid which is usually formed by reacting an azide salt such as NaN_3 with a strong acid. [4]

N_3H can be represented by two possible Lewis structures in which the atoms can be arranged as NNNH.

Draw the **two** possible Lewis (electron dot) structures of N_3H and predict the N-N-H bond angle in each structure.

Lewis (electron dot) structure	Structure I:	Structure II:
N-N-H bond angle	………………………………………..	………………………………………..

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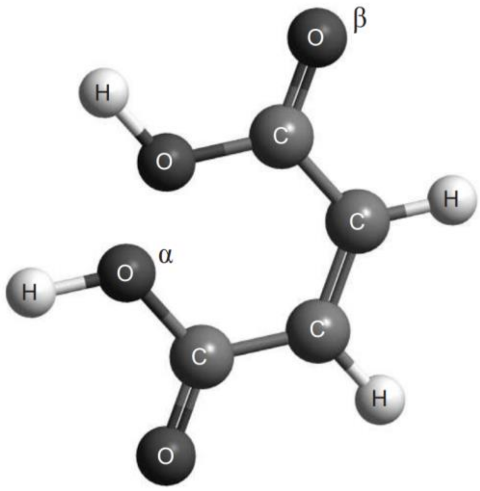
(Question 3 continued)

(b) The structure of *cis*-but-2-ene-1,4-dioic acid is shown below.



(i) Describe the covalent bond between carbon and hydrogen in the molecule above and how it is formed. [2]

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(ii) Deduce the hybridization of the oxygen atoms labelled α and β. [1]

α: ....

β: ....

(This question continues on the following page)

(Question 3 continued)

(iii) But-2-ene-1,4-dioic acid can also exist in the trans configuration. Suggest, with reasoning, whether the *cis* or *trans* isomer has a higher boiling point. [2]

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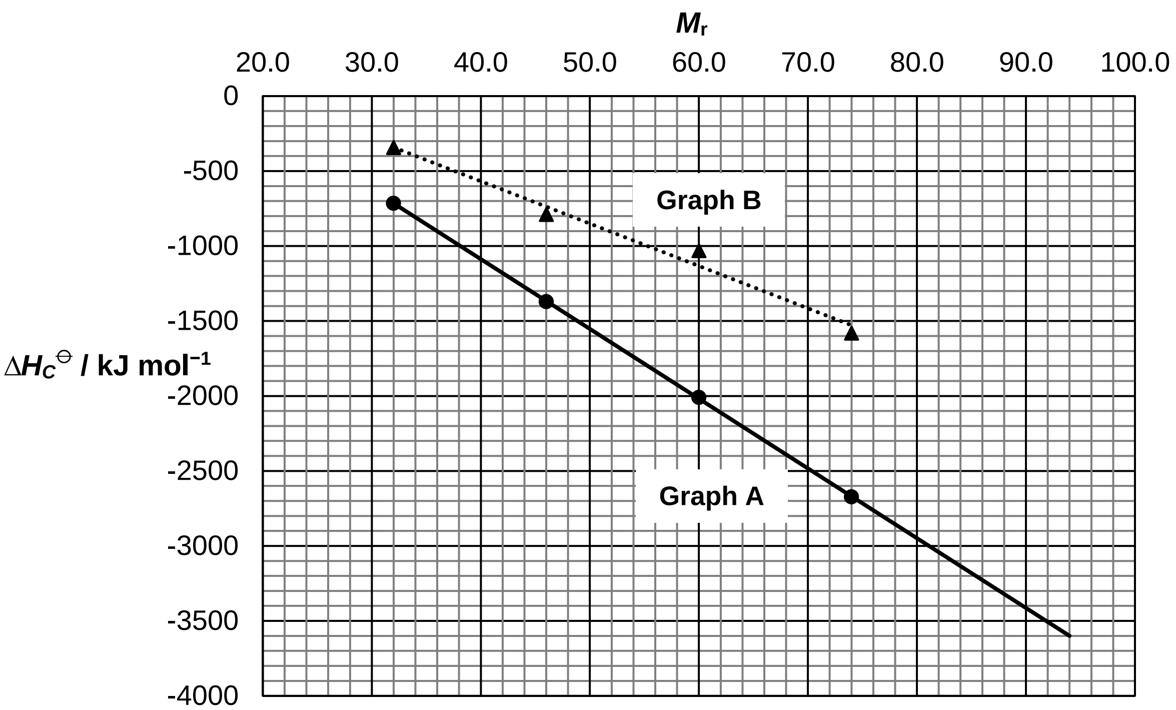
4. The standard enthalpies change of combustion, $\Delta H_C^{\ominus}$, and the relative molecular masses, M_r, of a series of alcohols are given and they are plotted in **Graph A** below:

Alcohol	**Methanol**	**Ethanol**	**Propan-1-ol**	**Butan-1-ol**
M_r	32.0	46.0	60.0	74.0
$\Delta H_C^{\ominus}$ / kJ mol^{-1}	−715	−1371	−2010	−2673



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(Question 4 continued)

(a) (i) Explain the linear relationship obtained in **Graph A**. [1]

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(ii) Calculate the relative molecular mass of pentan-1-ol and thus estimate $\Delta H_C^\ominus$ using **Graph A**. [2]

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(iii) Given the equation below, use your answer in **4(a)(ii)** and relevant data from section 12 of the data booklet, calculate the standard enthalpy change of formation of pentan-1-ol. [2]

$$C_5H_{11}OH\ (l) + \frac{15}{2}O_2\ (g) \rightarrow 5CO_2\ (g) + 6H_2O\ (l)$$

If you did not get an answer for **4(a)(ii)**, you may use $\Delta H_C^\ominus = -1000\ \text{kJ mol}^{-1}$ as the answer for **4(a)(ii)**.

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(Question 4 continued)

(b) To verify the trend obtained in **Graph A**, a student carried out a series of experiments in the laboratory to determine the enthalpy change of combustion of the alcohols using calorimetry. Her results are plotted in **Graph B**. [1]

Suggest **one** reason to account for the difference in the two graphs.

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(c) The combustion of methanol is found to be spontaneous at all temperatures.

(i) Hence predict the sign of the standard entropy change of combustion of methanol, giving a reason. [2]

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(ii) It is observed that methanol vapour is stable in air, but the mixture reacts quickly when ignited. Explain the observation. [2]

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5. Nitrogen(II) oxide is a colourless gas, which reacts with hydrogen as shown by the following equation.

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

(a) Explain why the order of a reaction cannot be obtained directly from the stoichiometric equation. [1]

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(b) (i) The reaction above is carried out using excess NO (g). The half-life of the hydrogen gas is found to be constant at 20 minutes. Sketch a graph in the axes given below to show how the rate of reaction would change with [H_2 (g)]. [1]

(ii) In another experiment, the initial [H_2 (g)] was kept constant while the initial [NO (g)] was doubled. The results show that the half-life of hydrogen gas decreased to 5 minutes. [2]

Deduce, with a reason, the order of reaction with respect to NO.

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(This question continues on the following page)

(Question 5 continued)

(iii) State the rate expression for the reaction. [1]

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(iv) A vessel with a volume of 2.00 dm^3 is filled with 0.400 mol of H_2 and 0.200 mol of NO at a temperature of 650 K, the initial rate of reaction is found to be 5.05×10^{-6} mol dm^{-3} s^{-1}. Determine the value of the rate constant, *k*, and state its units. [2]

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(c) A suggested mechanism for the reaction is as follows. [2]

$H_2 + NO \rightleftharpoons X$ fast step
$X + H_2 \rightarrow Y + H_2O$ slow step
$Y + NO \rightarrow N_2 + H_2O$ fast step

State and explain whether this mechanism matches the experimental rate expression in **5(b)(iii)**.

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(This question continues on the following page)

(Question 5 continued)

(d) State and explain how the use of a heterogeneous catalyst affect the rate of reaction between NO (g) and H_2 (g). [2]

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6. The water-gas shift reaction is used to produce hydrogen gas industrially by reacting carbon monoxide with water vapour.

$$CO\ (g) + H_2O\ (g) \rightleftharpoons CO_2\ (g) + H_2\ (g)$$

(a) (i) Deduce the equilibrium constant expression for this reaction. [1]

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(ii) 0.0197 mol of CO was mixed with 0.0394 mol of H_2O in a sealed vessel and allowed to reach equilibrium at 600 K. At equilibrium, 0.0191 mol of CO_2 was present. [2]

Calculate the value of K_c at 600 K.

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(This question continues on the following page)

(Question 6 continued)

(b) The value of K_c is 1.978 at 900 K. State and explain whether the forward reaction is exothermic or endothermic. [2]

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(c) Calculate the Gibbs free energy change, ΔG, for the reaction, in kJ, using sections 1 and 2 of the data booklet and the value of K_c in **6(b)**. Hence, comment on the spontaneity of the reaction. [2]

State your answer to three significant figures.

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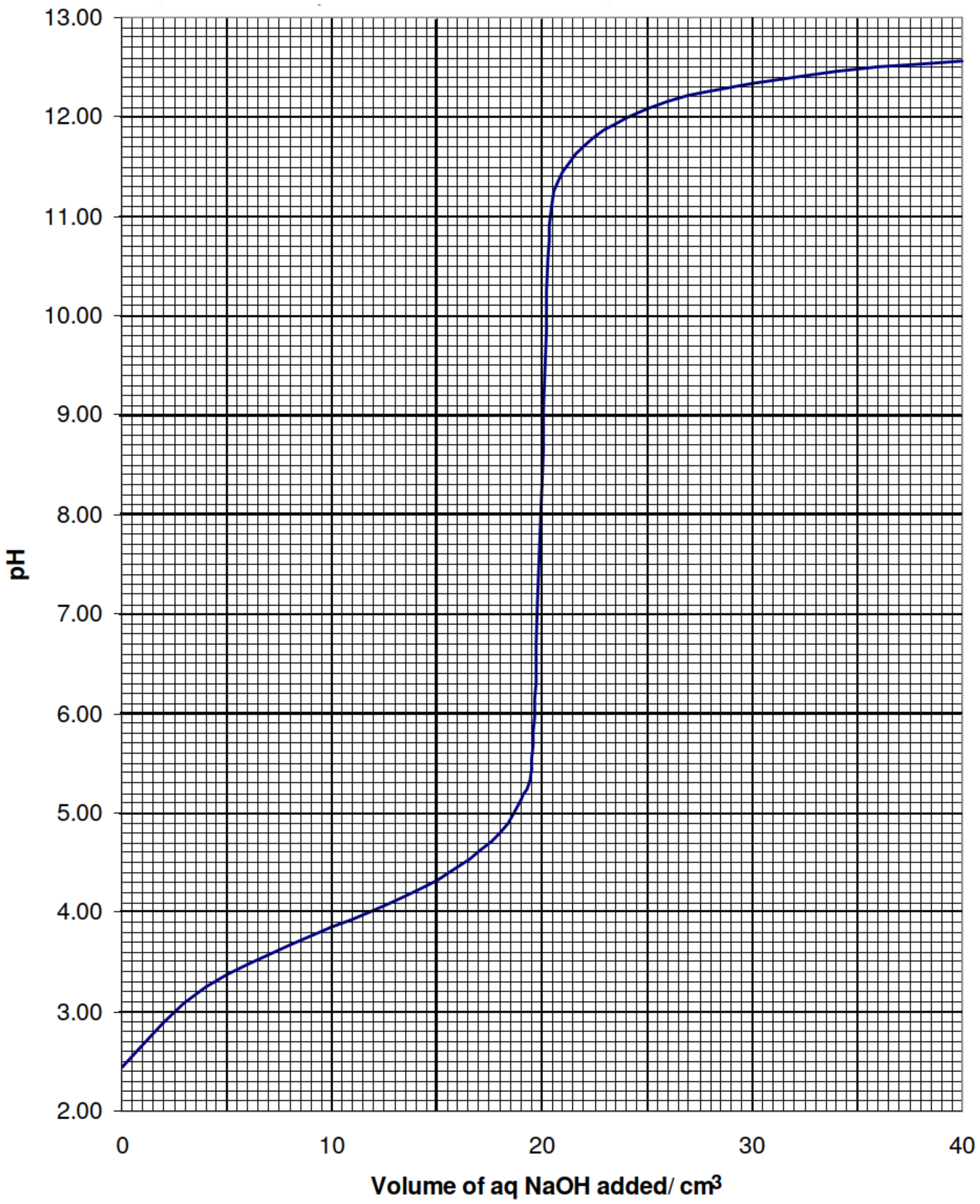
7. Lactic acid, $CH_3CH(OH)COOH$, a monobasic acid, is a chemical compound that plays a role in several biochemical processes.

0.100 mol dm^{-3} of an aqueous solution of lactic acid is titrated with aqueous sodium hydroxide and the following graph is obtained.



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(Question 7 continued)

(a) (i) State the equation for the reaction between $CH_3CH(OH)COOH$ and NaOH. [1]

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(ii) Using the titration curve and relevant calculation, show that lactic acid is a weak acid. [2]

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(iii) Identify the point from the graph where maximum buffer capacity was reached with a cross 'X' and hence determine the K_a of lactic acid. [2]

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(iv) Write an equation to explain why the pH at equivalence point is above 7. [1]

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(Question 7 continued)

(b) (i) NH_3 is amphiprotic. Outline what is meant by *amphiprotic*, and state the formulas of both species it is converted to when it behaves in this manner. [2]

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(ii) Ammonia can act as a Lewis base and a reducing agent. Study the following reactions and deduce with reason, the role of ammonia in each reaction.

Reaction 1: $NH_3 + BF_3 \rightarrow NH_3BF_3$ [2]

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Reaction 2: $NH_3 + HNO_2 \rightarrow N_2 + 2H_2O$ [2]

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8. A fuel cell uses the chemical energy of hydrogen or another fuel to cleanly and efficiently produce electricity. Due to its several benefits over the conventional combustion-based technologies currently used in many power plants and passenger vehicles, fuel cells are becoming increasingly popular.

The first alcohol to be used successfully in a fuel cell was methanol, CH_3OH. At the cathode, oxygen undergoes the following reaction:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

CH_3OH is oxidised at the anode producing CO_2 gas as one of the products.

(a) (i) Write the half-equation of CH_3OH to produce CO_2 at the anode. [1]

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(ii) The standard cell potential of the fuel cell is 1.18 V. Calculate the standard electrode potential, $E^\ominus$ of the CO_2/CH_3OH half cell using section 24 of the data booklet. [2]

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(Question 8 continued)

(iii) Fuel cells can operate at higher efficiencies and lower emissions than the conventional combustion engines used in coal power plants and motor vehicles. Hence, electric power plants and electric vehicles are getting increasingly popular. The U.S. Department of Energy (DOE) is working closely with its national laboratories, universities, and industry partners to overcome critical technical barriers to fuel cell development. [2]

Suggest and elaborate on **one** possible key challenge faced by the fuel cell industry.

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(b) An aqueous solution of magnesium chloride is electrolysed. Contrast the product obtained at the positive electrode (anode) if the concentration of aqueous magnesium chloride is increased from 0.5 mol dm^{-3} to 4 mol dm^{-3}. [3]

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9. (a) (i) Halogenoalkanes undergo nucleophilic substitution reactions with aqueous sodium hydroxide. [1]

State **one** reason why most halogenoalkanes are more reactive than alkanes.

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(ii) Explain the mechanism of the reaction between 1-bromopropane with aqueous sodium hydroxide using curly arrows to represent the movement of electron pairs and showing any stereochemical features of the reaction mechanism. [4]

(iii) Suggest, with a reason, whether polar, aprotic solvents or polar, protic solvents favour the reaction in **9(a)(ii)**. [2]

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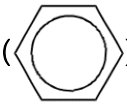
(Question 9 continued)

(b) Benzene is an aromatic hydrocarbon. State **two** physical evidences that support the structure of benzene (). [2]

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(c) (i) Benzene can be converted to nitrobenzene, $C_6H_5NO_2$. State an equation for the formation of NO_2^+. [1]

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(ii) Explain the mechanism for the nitration of benzene, using curly arrows to show the movement of electron pairs. [3]

(This question continues on the following page)

(Question 9 continued)

(d) Phenylamine can be obtained from nitrobenzene, through a two-step reaction. [2]

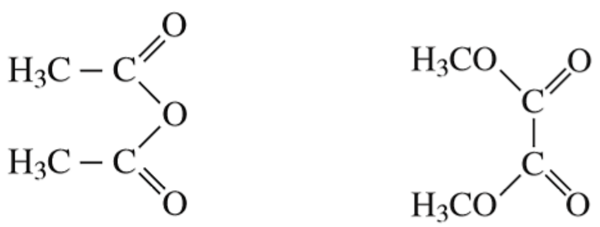
During the first step, tin reacts with nitrobenzene to form an intermediate ion and tin(II) ions in an acidic medium.
In the second stage, the intermediate ion is converted to phenylamine in the presence of hydroxide ions.

Formulate the equation for each stage of the reaction.

Stage one : ....

Stage two : ....

10. (a) ^{1}H NMR spectroscopy is often very useful in distinguishing compounds with similar structures, such as compounds **X** and **Y** with the structures shown below.



X **Y**

(i) Name the reference compound commonly used in ^{1}H NMR. [1]

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(This question continues on the following page)

(Question 10 continued)

(ii) Compare and contrast the [1]H NMR spectra of compounds **X** and **Y**, using section 27 of the data booklet. [3]

One similarity:

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One difference:

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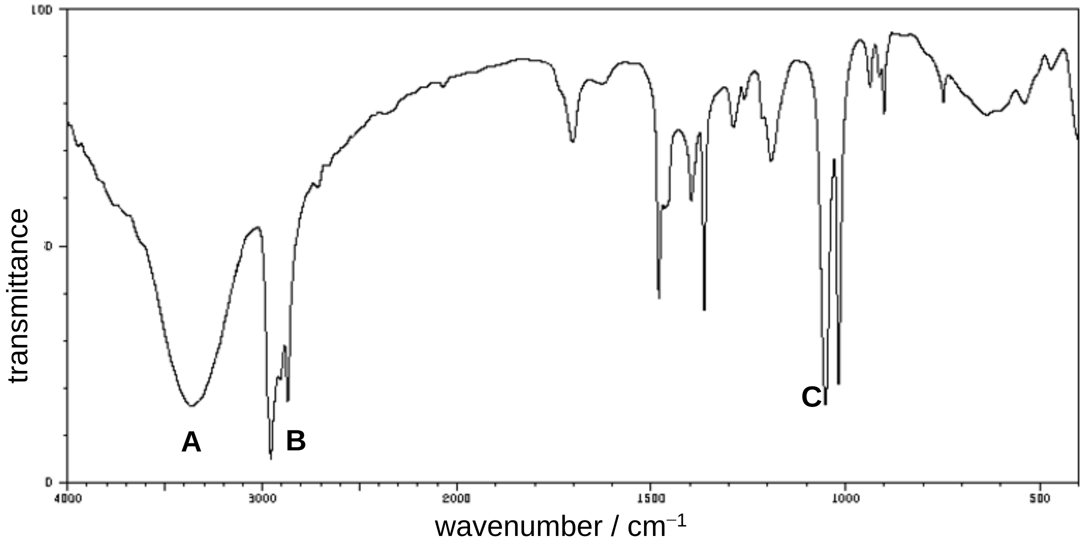
(b) The infrared (IR) spectrum of an unknown compound **W**, with empirical formula $C_5H_{12}O$, is presented below.



(i) Identify the bond responsible for each of the absorptions labelled **A**, **B** and **C**. [2]

A ....

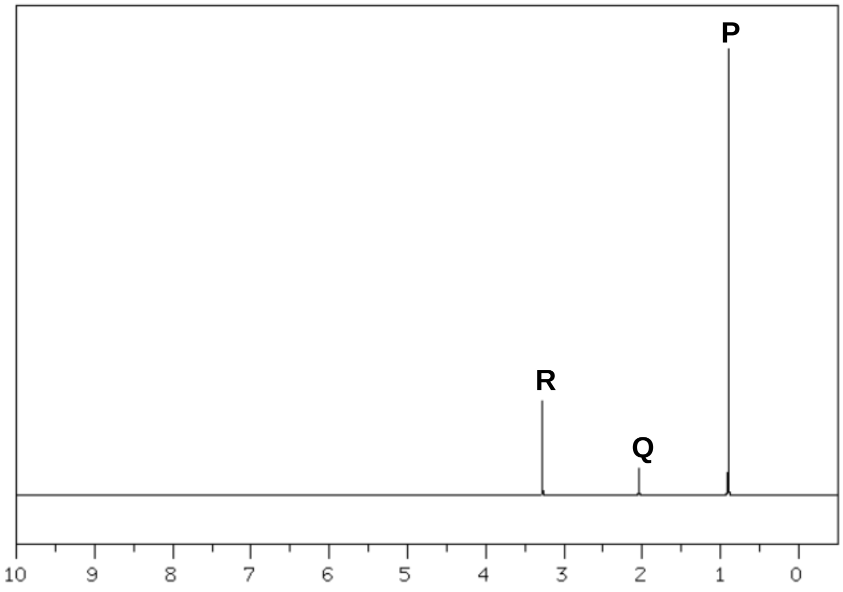
B ....

C ....

(This question continues on the following page)

(Question 10 continued)

(ii) The high-resolution ^{1}H NMR spectrum of compound **W** is shown alongside a table with relative peak areas and splitting patterns. [2]



Chemical shift / ppm

[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

Peak	Relative peak area	Splitting pattern
P	9	singlet
Q	1	singlet
R	2	singlet

Deduce the structural formula of **W**.

End of Paper