2020. M34 2020L022A1EL

Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2020

CHEMISTRY – HIGHER LEVEL

3 hours

400 MARKS

Answer **eight** questions in all.

These must include at least **two** questions from **Section A**.

All questions carry equal marks (50).

The information below should be used in your calculations.

Relative atomic masses (rounded): H = 1.0, C = 12, O = 16, Na = 23, Al = 27, K = 39, Mn = 55

Avogadro constant = 6.0×10^{23} mol^{-1}

Molar volume at s.t.p. = 22.4 litres

Universal gas constant = 8.3 J K^{-1} mol^{-1}

The use of the *Formulae and Tables* booklet approved for use in the State Examinations is permitted. A copy may be obtained from the superintendent.

Section A

Answer at least <u>two</u> questions from this section. See page 1 for full instructions.

1. Washing soda is a cheap, household chemical used for laundry, removing grease and softening water. Washing soda crystals are hydrated sodium carbonate (**$Na_2CO_3.xH_2O$**). The crystals effloresce (lose some water of crystallisation) in dry air becoming powdery in the process.

To determine the average value of ***x*** in the formula **$Na_2CO_3.xH_2O$** for a sample of washing soda, 3.46 g of the crystals were dissolved in deionised water and made up to exactly 250 cm^3 of solution. 25.0 cm^3 volumes of this solution were pipetted into a conical flask and titrated with a previously standardised hydrochloric acid solution using a suitable indicator.

The balanced equation for the titration reaction is:

$$2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$$

(*a*) Identify a primary standard that could have been used to standardise the hydrochloric acid solution for this analysis. (5)

(*b*) Describe how the 250 cm^3 solution of washing soda was prepared starting with 3.46 g of washing soda measured out accurately on a weighing boat. (12)

(*c*) (*i*) Name a suitable indicator for this titration.

(*ii*) Justify your choice of indicator.

(*iii*) Using this indicator what colour change was observed in the conical flask at the end point? (12)

(*d*) On average 21.5 cm^3 of 0.12 M hydrochloric acid solution were required to completely neutralise 25.0 cm^3 of the washing soda solution.

Find by calculation

(*i*) the average number of moles of **HCl** used up in a titration,

(*ii*) the number of moles of **Na_2CO_3** neutralised in each titration,

(*iii*) the number of moles of **Na_2CO_3** in 250 cm^3 of the washing soda solution,

(*iv*) the mass of **Na_2CO_3** in 250 cm^3 of the washing soda solution,

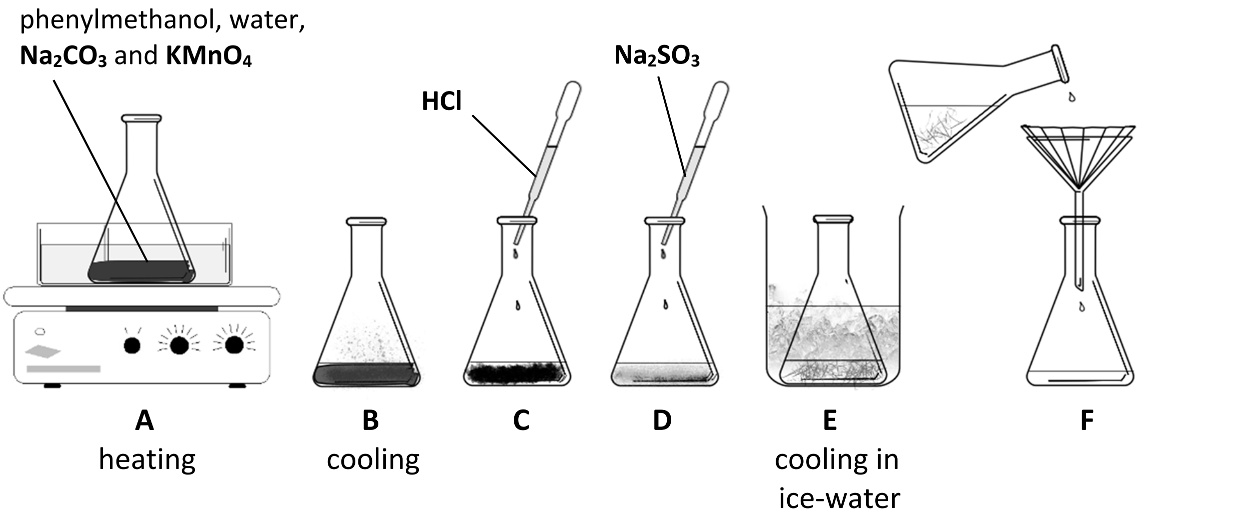
(*v*) the mass of water of crystallisation and hence the number of moles of water in 3.46 g of the crystals,

(*vi*) the ratio of moles of water of crystallisation to moles of **Na_2CO_3** in the crystals and hence the value of ***x*** to the nearest whole number. (21)

2. Benzoic acid is synthesised by the oxidation of phenylmethanol (benzyl alcohol) with $\mathbf{KMnO_4}$ in alkaline conditions. The overall balanced equation for the oxidation reaction is:

$$3C_6H_5CH_2OH + 4KMnO_4 \rightarrow 3C_6H_5COOH + 4MnO_2 + H_2O + 4KOH$$

The stages of the synthesis are illustrated in diagrams **A** to **F** below.
Stages **A** and **B** are the oxidation stages.
Concentrated **HCl** is added at stage **C** and concentrated $\mathbf{Na_2SO_3}$ solution is added at stage **D**.
Benzoic acid crystals are collected at stage **F.**



(*a*) (*i*) Describe the appearance of phenylmethanol at room temperature.

(*ii*) Name a suitable piece of apparatus to measure accurately 1.5 cm^3 of phenylmethanol. (5)

(*b*) How does the appearance of the reaction mixture change when the phenylmethanol is heated along with potassium manganate(VII) solution to which sodium carbonate has been added? (6)

(*c*) Describe what is observed during stages **D** and **E**.
Explain these observations. (12)

(*d*) (*i*) Name a suitable technique to purify the benzoic acid crystals collected at stage **F**.

(*ii*) Describe how you measured the melting point of a sample of benzoic acid crystals. (12)

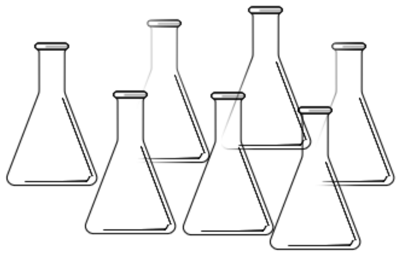
(*e*) A student used a solution containing 3.16 g of potassium manganate(VII) to oxidise 1.5 cm^3 phenylmethanol (density 1.04 g cm^{-3}) as described above.

(*i*) Show by calculation whether there is sufficient potassium manganate(VII) to oxidise all the phenylmethanol according to the balanced equation above.

(*ii*) Find the theoretical yield in grams of benzoic acid. (15)

3. The effect of temperature on the rate of the reaction between a sodium thiosulfate solution and a hydrochloric acid solution was investigated. In each run, a stopwatch was started as 10 cm^3 of 3.0 M hydrochloric acid solution were added to a reaction flask containing 100 cm^3 of a 0.05 M sodium thiosulfate solution. The temperature of the reaction mixture was recorded immediately after the addition of the **HCl**. In each run, the time (t) taken for the reaction to reach the same observable stage was measured. The reciprocal of this time may be taken as a measure of the initial rate of the reaction ($r = 1/t$). The table contains the data collected by a student who used a set of identical conical flasks for Runs 1 to 7.

Run	Temperature (°C)	t (s)	$r = 1/t$ (s^{-1})
1	0	500	0.002
2	13	200	
3	22	109	
4	33	56	
5	40	34	
6	51	16	
7	59	9	



(*a*) With the aid of a labelled diagram describe a method for adjusting and measuring the temperature of the reaction mixture for the runs above room temperature. (9)

(*b*) (*i*) What was observed in the reaction flasks during each run?

(*ii*) Describe how this observation was used to obtain the reaction times. (9)

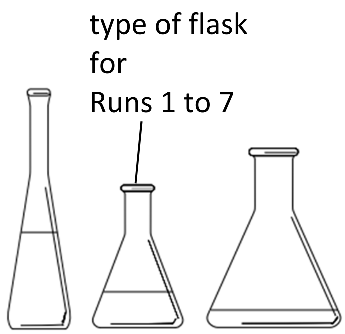
(*c*) Copy the last column of the table into your answerbook and fill in the missing rates correct to three decimal places. (6)

(*d*) (*i*) Plot a graph of initial reaction rate (r) *versus* temperature.

(*ii*) Use your graph to find an approximate value for x in the following statement: 'The rate of this reaction doubles for every x °C rise in temperature.'

(*iii*) Explain this result. (21)

(*e*) The student then carried out another run (Run 8) at 40 °C but in a conical flask of different shape to those used previously. As before, 10 cm^3 of 3.0 M hydrochloric acid were added to 100 cm^3 of 0.05 M sodium thiosulfate solution. The reciprocal of t in Run 8 was 0.015 s^{-1}.



(*i*) Show, by plotting it, whether the corresponding data point (40, 0.015) lies on the curve you have plotted.

(*ii*) Was the depth of liquid in the flask used in this Run 8 greater or less than in the original flasks? Justify your answer. (5)

Section B

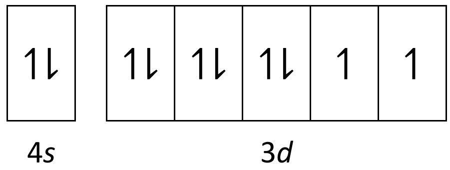
See page 1 for instructions regarding the number of questions to be answered.

4. Answer **eight** of the following (*a*), (*b*), (*c*), etc. (50)

(*a*) Draw a labelled diagram of Thomson's plum-pudding model of the atom.

(*b*) The diagram represents the 10 electrons in the 4*s* and 3*d* sub-levels of a neutral atom of a certain element in its ground state.

What is the element?



(*c*) What isotope is produced when the nucleus of an $^{241}_{95}\mathbf{Am}$ atom releases an alpha particle?

(*d*) Write the chemical formulae for:

(*i*) magnesium sulfite,

(*ii*) copper(II) oxide.

(*e*) Give two possible shapes of a covalent molecule with the general formula $\mathbf{QX_3}$.

(*f*) Each of the small metal canisters shown in the photograph contains 0.36 moles of carbon dioxide. The contents of one canister were released into a flat bicycle tube. The gas inflated the tube to a volume of 1.0×10^{-3} m^3 at a temperature of 293 K. Calculate the pressure of the gas inside the tube correct to two significant figures.

(*g*) How can a catalyst lower the activation energy of a reaction?

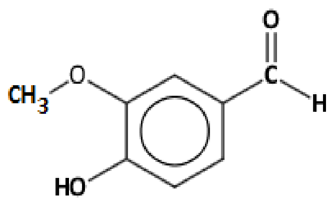
(*h*) Under what circumstances do ionic compounds conduct electricity?

(*i*) Identify the compound that is the main component of the limescale deposit in a kettle used in a hard water area.

(*j*) Copy into your answerbook the structure of vanillin, the main component of the extract of the vanilla bean.

(*i*) Circle the aldehyde group.

(*ii*) Write the molecular formula for vanillin.



(*k*) Answer part **A** *or* part **B**.

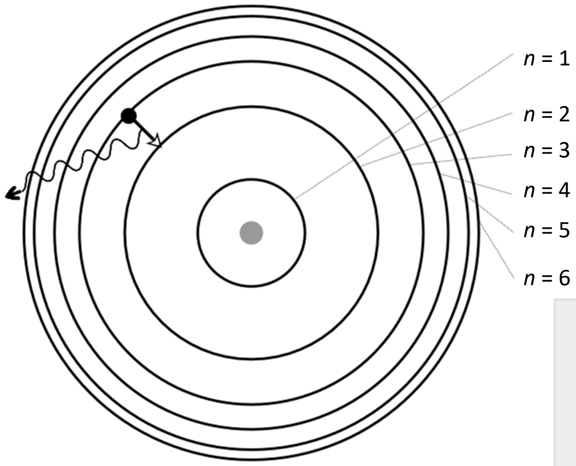
A Write a balanced equation for the photo-dissociation of ozone.

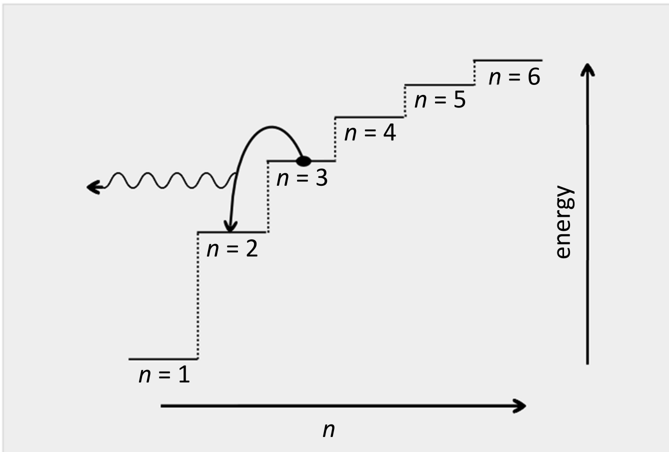
or

B Draw the structure of the monomer used to make poly(phenylethene).

5. The reactivity of an element is determined by the number and arrangement of electrons around the nucleus in each of its atoms. Around 1913 Bohr proposed that electrons in an atom occupied energy levels. Later sub-levels and orbitals were introduced into atomic theory to account for certain experimental observations.

The diagrams below are two different representations of the first six energy levels in the electron cloud of a hydrogen atom.





(*a*) What is an electron? (5)

(*b*) (*i*) Why might the electron in a hydrogen atom *not* occupy the *n* = 1 energy level?

(*ii*) What colour light is associated with the electron in a hydrogen atom moving from *n* = 3 to *n* = 2?

(*iii*) Name the series of visible lines in the hydrogen emission spectrum. (9)

(*c*) (*i*) How many sub-levels are associated with the *n* = 3 energy level?

(*ii*) What is an atomic orbital?

(*iii*) How many orbitals are associated with the *n* = 2 energy level?

(*iv*) What is the maximum number of electrons that can occupy the *n* = 3 energy level in a multi-electron atom? (15)

(*d*) Write *s*, *p* electron configurations for beryllium, neon, magnesium and krypton.

Refer to these electron configurations to explain

(*i*) why the Group 18 elements neon and krypton are chemically inert,

(*ii*) why the Group 2 elements beryllium and magnesium are reactive.

Why is magnesium more reactive than beryllium? (21)

6. Petrol is mostly a mixture of hydrocarbons, obtained from the fractional distillation of crude oil, and is in high demand as a fuel for cars. To avoid <u>knocking in the engine</u>, petrol must have a suitable <u>octane number</u>. Various oil refining processes, all requiring catalysts, are represented by the balanced equations below and these processes supply petrol suitable for high efficiency car engines.

$$\mathbf{C_{14}H_{30} \rightarrow C_2H_4 + 2X + C_6H_{14}}$$

$$\mathbf{CH_3(CH_2)_5CH_3 \rightarrow C_6H_5CH_3 + 4H_2}$$

$$\mathbf{CH_3(CH_2)_6CH_3 \rightarrow CH_3CH(CH_3)CH_2C(CH_3)_2CH_3}$$

(*a*) Explain the underlined terms. (8)

(*b*) (*i*) Name the type of oil refining reaction in each of the three equations above.

(*ii*) Deduce the formula of hydrocarbon **X**.

(*iii*) Give the systematic IUPAC name for the product in the third equation. (15)

(*c*) Petrol may contain oxygenates.

(*i*) Give an example of an oxygenate used in petrol.

(*ii*) Why are oxygenates added to petrol? (6)

(*d*) (*i*) Define heat of formation.

(*ii*) The heats of formation of propane, carbon dioxide and water are –104.7, –393.5 and –285.8 kJ mol^{-1} respectively. Write a balanced equation for the combustion of propane in a plentiful oxygen supply and use the data provided to calculate the heat of combustion of propane. (21)

7. (*a*) According to Brønsted-Lowry theory, what is an acid?
How does this theory distinguish between a strong and a weak acid? (8)

(*b*) What is (*i*) the conjugate acid, (*ii*) the conjugate base, of $\mathbf{HSO_4^-}$? (6)

When carbon dioxide is pumped into still mineral water it becomes sparkling water. The information shown in the table was given on the label of a bottle of sparkling mineral water.

Typical Analysis	
$\mathbf{Ca^{2+}}$	164 mg/l
$\mathbf{Mg^{2+}}$	50 mg/l
$\mathbf{HCO_3^-}$	243 mg/l
$\mathbf{NO_3^-}$	3 mg/l
$\mathbf{SO_4^{2-}}$	402 mg/l
$\mathbf{Cl^-}$	49 mg/l
pH	5.6
pH at source	7.2

(*c*) Describe how you could test a sample of this mineral water for the presence of the sulfate ion. (6)

(*d*) The pH of the sparkling water is 5.6 while the pH of the source water was 7.2. Calculate

(*i*) the $\mathbf{H_3O^+}$ ion concentration of the *sparkling* water,

(*ii*) the $\mathbf{OH^-}$ ion concentration of the *source* water. (12)

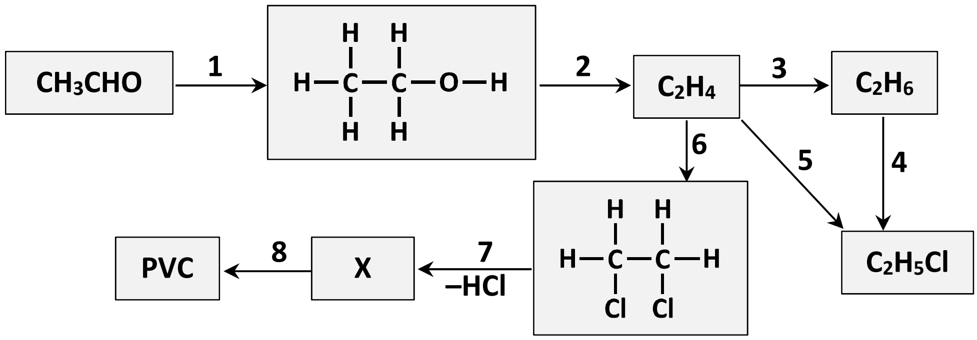
An acid-base indicator, which is a weak acid, may be represented by **HA**. The indicator is red in its undissociated form and yellow in the form $\mathbf{A^-}$.

(*e*) Calculate the pH of an aqueous 1.5×10^{-3} M solution of the indicator which has an acid dissociation constant (K_a) of 4.0×10^{-4}. (6)

(*f*) (*i*) Write an equilibrium equation for the dissociation of the indicator in water.

(*ii*) What is observed when a few drops of the indicator are added to a solution of a strong base? Explain your answer. (12)

8. Study the reaction scheme and answer the questions below.



(*a*) Identify in the scheme (*i*) a substitution reaction, (*ii*) an addition reaction, (*iii*) an elimination reaction. (9)

(*b*) (*i*) What reagent and catalyst can be used in conversion **1**?

(*ii*) Copy the structure of ethanol and identify clearly the bonds formed during conversion **1**. (12)

(*c*) Identify an organic substance in the scheme that is highly soluble in water.

Justify your answer. (6)

(*d*) (*i*) Identify compound **X**.

(*ii*) How does the geometry around the carbon atoms change during conversion **7**?

(*iii*) Draw the structure of two repeating units of the polymer **PVC**. (12)

(*e*) Describe a mechanism, that involves ions, for conversion **6**. (11)

9. When 3.0 moles of carbon monoxide and 1.0 moles of steam were mixed together in a container of fixed volume *V*, and in the presence of a suitable catalyst, the following chemical equilibrium was established at a temperature of 800 K.

$$CO_{(g)} + H_2O_{(g)} \rightleftharpoons CO_{2\,(g)} + H_{2\,(g)} \quad \Delta H = -41.2 \text{ kJ mol}^{-1}$$

(*a*) Explain *chemical equilibrium*.

Why is a chemical equilibrium described as *dynamic*?

State Le Châtelier's principle. (14)

(*b*) Write the equilibrium constant (K_c) expression for the reaction above. (6)

(*c*) The equilibrium constant for this reaction at 800 K is 4.0.
Calculate the number of moles of carbon monoxide in the equilibrium mixture at this temperature. (12)

(*d*) Predict the effect, if any, of adding more steam at 800 K to the equilibrium mixture

(*i*) on the value of K_c,

(*ii*) on the equilibrium yield of hydrogen.

Justify your prediction in each case. (12)

(*e*) State and explain the effect on the value of K_c of increasing the equilibrium temperature. (6)

10. Answer any **two** of the parts (*a*), (*b*) and (*c*). (2 × 25)

(*a*) Biochemical oxygen demand (BOD) of wastewater is lowered in sewage treatment by decreasing the quantities of suspended and dissolved organic matter.

(*i*) Define BOD.

(*ii*) What happens during the primary stages of sewage treatment?

(*iii*) What happens during the secondary stages of sewage treatment?

(*iv*) Under what circumstances is tertiary treatment considered desirable?

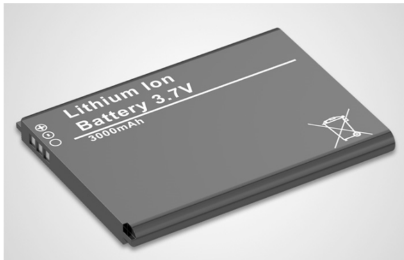
(*v*) Why is tertiary treatment not always carried out, even when desirable?

(*vi*) What could a negative environmental impact be if tertiary treatment were not carried out where desirable? (25)

(*b*) Define oxidation in terms of

(*i*) electron transfer,

(*ii*) change in oxidation number.



The 2019 Nobel Prize for Chemistry was awarded to three scientists for their work in developing rechargeable lithium ion batteries for use in modern devices, e.g. smart-phones and electric vehicles.

The balanced equation for the reaction that takes place when one type of lithium ion rechargeable battery supplies electricity is as follows:

$$\mathbf{LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2}$$

(*iii*) Assign oxidation numbers and determine which element is reduced in this reaction.

(*iv*) Identify which element acts as the oxidising agent.

(*v*) Using oxidation numbers, or otherwise, balance the following redox reaction that occurs when a lead-acid rechargeable battery supplies electricity:

$$\mathbf{Pb + PbO_2 + H^+ \rightarrow Pb^{2+} + H_2O}$$

(*vi*) Why is the recycling of batteries desirable? (25)

(*c*) Aluminium carbide reacts with water forming aluminium hydroxide and methane gas according to the following balanced equation.

$$\mathbf{Al_4C_3}\ _{(s)} + \mathbf{12H_2O}\ _{(l)} \rightarrow \mathbf{4Al(OH)_3}\ _{(s)} + \mathbf{3CH_4}\ _{(g)}$$

When a certain mass of aluminium carbide had reacted, according to the equation above, there were 3.6×10^{23} atoms of hydrogen in the aluminium hydroxide produced.

(*i*) What mass of $\mathbf{Al_4C_3}$ reacted?

(*ii*) What volume of methane, measured at s.t.p., was produced in the reaction?

(*iii*) Find the volume of water (density 1.0 g cm^{-3}) used up in the reaction. (25)

11. Answer any **two** of the parts (*a*), (*b*) and (*c*). (2 × 25)

(*a*) Consider the data shown below for a number of simple hydrides.

Hydride formula	Hydride name	Boiling point (°C)	Relative molecular mass
CH_4	methane	–161.5	16
H_2O	water	100.0	18
H_2S	hydrogen sulfide	−60.0	34
H_2Se	hydrogen selenide	−41.3	81
H_2Te	hydrogen telluride	−2.2	129.6

(*i*) Define electronegativity.

(*ii*) Hydrogen bonding accounts for the significantly higher boiling point of water compared to that of methane despite their similar relative molecular masses. Describe, with the aid of a diagram, how hydrogen bonding arises between water molecules. (12)

(*iii*) Why is water the only hydride in the table that exhibits strong hydrogen bonding?

(*iv*) Why is the boiling point of hydrogen selenide higher than that of hydrogen sulfide?

(*v*) Explain why, although carbon and selenium have the same electronegativity value, $\mathbf{CH_4}$ is almost completely insoluble in water and $\mathbf{H_2Se}$ is slightly soluble in water. (13)

(*b*) The percentage composition by mass of a pure, colourless liquid is 40.0% carbon, 6.67% hydrogen and 53.33% oxygen. The mass spectrum of the unknown substance was recorded and indicated that the relative molecular mass of the compound was 60. The infrared spectrum of the unknown substance was also recorded and indicated that there was a carbonyl group in the molecular structure of the compound.

(*i*) Find by calculation the empirical formula of the compound.

(*ii*) What molecular formula is suggested by the empirical formula and the mass spectrum result together? (15)

(*iii*) Give the systematic IUPAC names *or* draw the structures for two compounds with this molecular formula that contain a carbonyl group.

(*iv*) What conclusion can be reached if there was effervescence when a drop of the unknown liquid was added to a little damp, solid $\mathbf{Na_2CO_3}$ on a clock glass? (10)

(*c*) Answer part **A** *or* part **B**.

A

Oxygen gas can be prepared in the school laboratory by the catalytic decomposition of hydrogen peroxide or by the electrolysis of acidified water. However, for large-scale use, oxygen gas is not usually produced by a chemical reaction but is extracted from the other gases in air.

(*i*) Give one use for oxygen other than as a respiratory gas or to aid breathing.

(*ii*) Describe the stages of the industrial separation of oxygen from air. (15)

(*iii*) Identify the major co-product of this industrial process.

(*iv*) Give a use for the co-product.

(*v*) Explain why the co-product is chemically inert. (10)

or

B

The photograph shows the *Atomium* in Brussels. The Atomium represents the crystal structure of iron magnified about 165 billion times. Each of the nine spheres, which represent iron atoms, was originally clad in sheets of anodised aluminium. The aluminium has now been replaced with stainless steel cladding.

(*i*) What is meant by corrosion of a metal?

(*ii*) Compare the abilities of pure iron and pure aluminium to resist corrosion. (10)

(*iii*) What is the difference between iron and steel?

(*iv*) What is meant by anodising aluminium?

(*v*) Why can metals conduct electricity? (15)

Leaving Certificate – Higher Level

Chemistry

3 hours