Coimisiún na Scrúduithe Stáit
State Examinations Commission

LEAVING CERTIFICATE EXAMINATION, 2026

CHEMISTRY – HIGHER LEVEL

TUESDAY, 16 JUNE – AFTERNOON, 2:00 to 5:00

400 MARKS

Answer any **eight** questions.

All questions carry equal marks (50).

The information below should be used in your calculations.

Relative atomic masses (rounded): H = 1, C = 12, N = 14, O = 16, Na = 23, K = 39, Mn = 55

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

Molar volume at room temperature and pressure = 24.0 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.

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Section A

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

1. A student carried out an experiment to determine the amount of water of crystallisation in a sample of hydrated sodium carbonate (washing soda).

5.02 g of hydrated sodium carbonate (**$Na_2CO_3.xH_2O$**) was placed in a small beaker. The solid was then transferred to a 250 cm^3 volumetric flask and made up to the mark using deionised water.

20.0 cm^3 portions of this solution were transferred to a conical flask and titrated against a previously standardised 0.10 M hydrochloric acid (**HCl**) solution.

On average, 28.35 cm^3 of 0.10 M hydrochloric acid solution were required to neutralise the 20.0 cm^3 of the sodium carbonate (**Na_2CO_3**) solution.

The titration reaction is described by the following balanced chemical equation:

$$\mathbf{2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2}$$

(*a*) (*i*) Describe a suitable method to accurately transfer all the hydrated sodium carbonate from the beaker to the volumetric flask.

(*ii*) Explain why hydrated sodium carbonate (**$Na_2CO_3.xH_2O$**) is not considered a primary standard. (9)

(*b*) (*i*) Describe how the burette was rinsed before use.

(*ii*) State two precautions that should be taken as the end point of the titration is approached to ensure an accurate titration result. (12)

(*c*) (*i*) Identify a suitable indicator for use in this titration.

(*ii*) State the colour change that would be observed at the endpoint in this titration. (9)

(*d*) (*i*) Calculate the number of moles of **HCl** present in 28.35 cm^3 of the 0.10 M **HCl** solution.

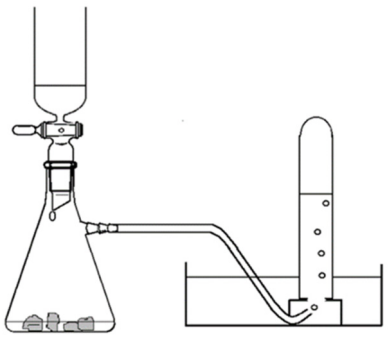
(*ii*) Calculate the number of moles of **Na_2CO_3** in the 250 cm^3 solution.

(*iii*) Calculate the mass of **Na_2CO_3** in the 250 cm^3 solution.

(*iv*) Calculate number of moles of water of crystallisation in the sample of **$Na_2CO_3.xH_2O$**.

(*v*) Determine the value of **x**, the average number of water molecules in the formula **$Na_2CO_3.xH_2O$**. (20)

2. (*a*) Ethyne gas (C_2H_2) was prepared in a school laboratory and collected by displacement of water as shown.



(*i*) Identify the two reactants used in the preparation of ethyne gas.

(*ii*) Explain the principle that allows ethyne to be collected by displacement of water.

(*iii*) State one precaution that should be taken to ensure a pure sample of ethyne gas is collected.

(*iv*) Identify a reagent that could be used to show ethyne is unsaturated.

(*v*) State the colour change observed for the reagent you have identified. (22)

(*b*) A sample of soap was prepared by a student by refluxing vegetable fat with excess sodium hydroxide in the presence of a suitable solvent.

(*i*) Name the type of reaction that occurred during reflux.

(*ii*) Identify a suitable solvent for use in the preparation of soap.

The solvent was removed by distillation.

(*iii*) Why was it desirable to remove the solvent after the reflux?

(*iv*) How was the soap isolated from the other substances left in the reaction mixture? (15)

(*c*) Ethanoic acid reacts with excess magnesium metal according to the following equation:

$$\mathbf{2CH_3COOH + Mg \rightarrow X + H_2}$$

(*i*) Identify **X**, that is produced during the above reaction.

(*ii*) 15 cm^3 of a 5% (w/v) solution of ethanoic acid was reacted with excess magnesium metal. Calculate the volume of hydrogen gas ($\mathbf{H_2}$) produced at room temperature and pressure. (13)

3. (*a*) A colorimeter or comparator can be used to measure the concentration of free chlorine in swimming pool water.

(*i*) What is the general principle of all colorimetric experiments?

(*ii*) Why is chorine added to swimming pool water?

(*iii*) Identify the free chlorine species present in swimming pool water.

(*iv*) Identify a suitable reagent(s) to test for free chlorine in swimming pool water.

(*v*) State the colour change that occurs when the reagents identified in (*iv*) react with free chlorine. (20)

(*b*) The total mass of *suspended* and *dissolved* solids in a 1250 cm^3 sample of swimming pool water was 1.750 g. The concentration of total *suspended* solids was 520 p.p.m.

(*i*) Describe a suitable method that could be used to measure the concentration of total *suspended* solids in the water sample.

(*ii*) Calculate the concentration of *dissolved* solids in p.p.m. (18)

(c) The type and quantities of *dissolved* solids found in swimming pool water can vary depending on the treatment chemicals used and the source of the water. Examples include sodium chloride, sodium sulfate and sodium nitrate.

(*i*) Describe a chemical test to confirm the presence of nitrate ions in the water sample.

(*ii*) Which of the two remaining salts can be identified by the addition of a solution of silver nitrate (**$AgNO_3$**)? What observation indicates a positive test result?

(12)

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*) How many (*i*) protons, (*ii*) electrons are present in the ion $\mathbf{Co^{2+}}$?

(*b*) Name the scientist who determined

(*i*) the *e*/*m* of the electron,

(*ii*) the magnitude of charge on an electron.

(*c*) Write a balanced equation for the beta decay of a carbon–14 nucleus.

(*d*) Account for the difference in bond angle between $\mathbf{BeCl_2}$ (180°) and $\mathbf{H_2O}$ (104.5°).

(*e*) Calculate the relative atomic mass, correct to two decimal places, of a sample of chlorine containing 75.76% of the chlorine–35 isotope and 24.24% of the chlorine–37 isotope.

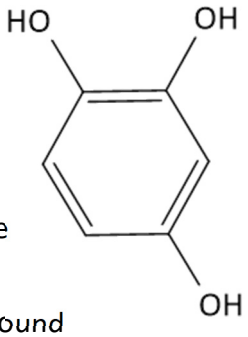
(*f*) Identify (*i*) the conjugate acid, (*ii*) conjugate base of $\mathbf{HPO_4^{2-}}$.

(*g*) State the principle of the separation of the components in a mixture using chromatography.

(*h*) Identify a substance

(*i*) used in water treatment to increase the pH of water,

(*ii*) used to fluoridate drinking water.



(*i*) Calculate the number of molecules of hydroxyhydroquinone, whose structure is shown on the right, in a cup of espresso coffee which contains 0.0017 g of hydroxyhydroquinone.

(*j*) Identify the elements produced at (*i*) the anode, (*ii*) the cathode during the electrolysis of potassium iodide.

(*k*) Draw the structure, including all atoms and all bonds, of the organic compound formed when methanol and ethanoic acid are reacted together in the presence of an acid catalyst.

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

A Describe how atmospheric nitrogen gas is fixed by lightning.

or

B State an example of (*i*) a molecular crystal, (*ii*) a covalent macromolecular crystal.

5. The arrangement of elements in the modern periodic table helps to predict patterns and trends in the properties of elements.

Refer to the data on page 80 and 81 of the *Formulae and Tables* booklet when answering the following questions.

(*a*) (*i*) Explain what is meant by the first ionisation energy of an element.

(*ii*) State two reasons why oxygen (**O**) has a higher first ionisation energy value than sulfur (**S**).

(*iii*) Explain why boron (**B**) has a lower first ionisation energy than beryllium (**Be**).

(*iv*) Which element would you expect to have the higher second ionisation energy sodium (**Na**) or magnesium (**Mg**)? Justify your answer. (21)

(*b*) (*i*) Explain what is meant by the term electronegativity.

(*ii*) Use electronegativity values to predict the type of bonding in a molecule of $\mathbf{AsH_3}$.

(*iii*) Draw a dot and cross diagram to show the arrangement of electrons in a molecule of $\mathbf{AsH_3}$.

(*iv*) Would you expect an $\mathbf{AsH_3}$ molecule to be polar or non-polar? Justify your answer.

(22)

(*c*) An element, **X**, has a low first ionisation energy and a low electronegativity value.

Predict whether element **X** would make a suitable oxidising agent or reducing agent. Justify your answer. (7)

6. Crude oil is a complex mixture of hydrocarbon molecules. In an oil refinery these molecules are separated into different fractions. Some of these fractions are useful but others need further chemical processing. For example, the unprocessed gasoline fraction cannot be used as petrol as it has a very low octane number.

(*a*) (*i*) Explain what is meant by the octane number of a fuel.

(*ii*) Identify the two reference hydrocarbons used to establish the octane number of a fuel.

(*iii*) State two structural features of molecule that would contribute to it having a high octane number. (15)

(*b*) Several processes are used in oil refining to increase the octane number of a fuel.

A $\mathbf{C_6H_{14} \rightarrow X + 4H_2}$

B $\mathbf{C_{18}H_{38} \rightarrow C_6H_{14} + C_4H_8 + C_2H_4 + 2Y}$

C $\mathbf{C_5H_{12} \rightarrow C_5H_{12}}$

(*i*) Name molecule **X** which is formed as part of process **A**.

(*ii*) Deduce the molecular formula for **Y**.

(*iii*) Name the homologous series to which **Y** belongs.

(*iv*) Draw the three possible isomers of the molecule $\mathbf{C_5H_{12}}$ including all atoms and bonds. (18)

(*c*) (*i*) Explain what is meant by the term heat of formation.

The Claus process is used in oil refining to convert hydrogen sulfide ($\mathbf{H_2S}$), a toxic gas, to sulfur (**S**) and steam ($\mathbf{H_2O}$). The reaction can be described by the following balanced chemical equation:

$$\mathbf{SO_{2(g)} + 2H_2S_{(g)} \rightarrow 3S_{(s)} + 2H_2O_{(g)}} \qquad \Delta H = -145.6 \text{ kJ mol}^{-1}$$

The heats of formation of sulfur dioxide ($\mathbf{SO_2}$) and steam ($\mathbf{H_2O}$) are –296.8 kJ mol^{-1} and –241.8 kJ mol^{-1} respectively.

(*ii*) Use the information above to calculate the heat of formation (ΔH) of hydrogen sulfide ($\mathbf{H_2S}$). (17)

7. Steam reforming is a common industrial method used for the production of hydrogen gas. A mixture of 7.6 moles of methane (**CH_4**) and 10.4 moles of steam (**H_2O**) were heated over a nickel catalyst in a sealed 4 litre container at temperature T_1. They reacted to form hydrogen gas (**H_2**) and carbon monoxide (**CO**). An equilibrium was established which is described by the following balanced chemical equation:

$$\mathbf{CH_4}_{(g)} + \mathbf{H_2O}_{(g)} \rightleftharpoons \mathbf{CO}_{(g)} + \mathbf{3H_2}_{(g)} \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

(*a*) (*i*) Explain what is meant by the term chemical equilibrium.

(*ii*) What effect does the use of a catalyst have on the position of the equilibrium? Explain your answer. (11)

(*b*) At equilibrium, at temperature T_1, there were 6.8 moles of carbon monoxide in the container.

(*i*) Calculate the number of moles of **CH_4** present in the equilibrium mixture.

(*ii*) Calculate the number of moles of **H_2O** present in the equilibrium mixture.

(*iii*) Calculate the number of moles of **H_2** present in the equilibrium mixture.

(*iv*) Write an expression for the equilibrium constant $\boldsymbol{K}_c$ for this reaction.

(*v*) Calculate the value of $\boldsymbol{K}_c$ for the equilibrium correct to one decimal place at temperature T_1. (21)

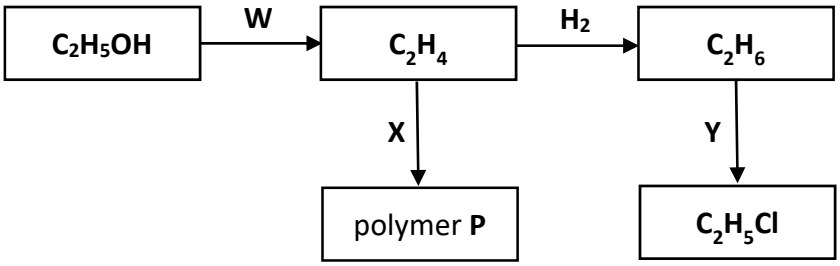
(*c*) (*i*) State Le Châtelier's principle.

(*ii*) Predict the effect on $\boldsymbol{K}_c$ if the same reaction is carried out at the same temperature T_1 but the initial concentrations of reactants are halved. Explain your answer.

When the mixture was allowed to come to equilibrium at temperature T_2 in the same 4 litre container it was observed that the value of $\boldsymbol{K}_c$ increased.

(*iii*) Which is the higher temperature, T_1 or T_2? Justify your answer. (18)

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



(*a*) (*i*) Name the homologous series to which **C_2H_5OH** belongs.

(*ii*) Identify the catalyst and conditions required for conversion **W** to take place.

(*iii*) Conversion **W** is an elimination reaction. State two features of conversion **W** that show it is an elimination reaction. (12)

(*b*) **C_2H_4** can undergo addition and polymerisation reactions.

(*i*) Draw two repeating units of the polymer formed when **C_2H_4** undergoes addition polymerisation, showing all atoms and all bonds.

(*ii*) Name the polymer produced in reaction **X**.

(*iii*) How does the geometry around the carbon atoms change during reaction **X**?

(*iv*) Explain how the nature of the bonding in **C_2H_4** enables it to undergo addition and polymerisation. (19)

(*c*) Reaction **Y** occurs via free radical substitution.

(*i*) Identify the reagent and conditions necessary for the formation of free radicals during the initiation stage of this reaction.

(*ii*) Is the formation of free radicals during the initiation stage an endothermic or exothermic process? Justify your answer.

(*iii*) Use balanced chemical equations to show the formation of free radicals during the two propagation reactions.

(*iv*) Explain why the addition of tetraethyl lead greatly speeds up reaction **Y**. (19)

9. (*a*) Nitrogen dioxide (NO_2) decomposes in the presence of a metal catalyst according to the following balanced chemical equation:

$$2NO_{2(g)} \rightarrow N_{2(g)} + 2O_{2(g)}$$

The following data were obtained at temperature *T* for the decomposition of NO_2 gas by a metal catalyst.

time (s)	0	50	100	300	400	600
concentration of NO_2 (mol L^{-1})	0.010	0.0079	0.0065	0.0038	0.0034	0.0030

(*i*) Plot a graph on graph paper of concentration versus time for the decomposition of NO_2 gas.

(*ii*) Calculate the instantaneous rate of decomposition at 300 s.

(*iii*) What effect, if any, would you expect an increase in temperature to have on the rate of decomposition? Justify your answer.

(*iv*) Show clearly on your graph the result you would expect to obtain if the surface area of the catalyst was doubled. (23)

(*b*) The reaction above is one of several that occur in the catalytic converters of cars and is an example of heterogenous catalysis.

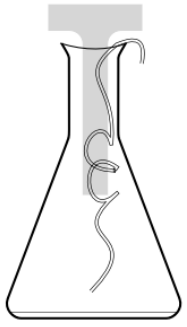
(*i*) Identify a metal that acts as catalyst in catalytic converters.

(*ii*) Use a balanced chemical equation to describe one other reaction that is catalysed by a catalytic converter.

(*iii*) Identify a substance which poisons the catalysts in a catalytic converter.

(*iv*) Explain how a catalytic poison reduces the efficiency of a catalyst. (15)

(*c*) The diagram shows the oxidation of methanol using platinum wire as catalyst.



(*i*) State one observation made during this experiment.

(*ii*) Why can this reaction also be described as an example of heterogenous catalysis?

(*iii*) Describe the mechanism by which the catalyst increases the rate of this reaction. (12)

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

(*a*) In 1861, Robert Bunsen and Gustav Kirchhoff used flame tests to study the line emission spectra of elements. Their work resulted in the discovery of a new element, rubidium (**Rb**).

(*i*) What is a line emission spectrum?

(*ii*) Describe a suitable method for distinguishing between metal salts using a flame test.

(*iii*) Name the instrument used for viewing the line emission spectra of elements.

(*iv*) Describe how line emission spectra occur.

(*v*) What evidence do line emission spectra provide for the existence of energy levels in atoms?

(*vi*) Explain why the line emission spectra of hydrogen and rubidium differ. (25)

(*b*) (*i*) Explain what is meant by the term ideal gas.

(*ii*) State two conditions under which real gases come closest to ideal behaviour.

(*iii*) Assuming ideal behaviour, calculate the volume occupied by 0.06 moles of a gas at a pressure of 99 kPa and a temperature of 25 °C.

At standard temperature and pressure the molar volume of ammonia (**NH_3**) may be 1.3% less than that of an ideal gas.

(*iv*) Explain why the molar volume of ammonia may be less than that of an ideal gas under these conditions. (25)

(*c*) Benzoic acid can be synthesised by the reaction of phenylmethanol **$C_6H_5CH_2OH$** with potassium permanganate **$KMnO_4$** in alkaline conditions. 6.32 g of **$KMnO_4$** were reacted with 2.70 cm^3 of **$C_6H_5CH_2OH$** (density = 1.04 g cm^{-3}). 1.97 g of pure benzoic acid was isolated. The reaction can be described by the following balanced chemical equation:

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

(*i*) Calculate the number of moles of **$C_6H_5CH_2OH$** present at the start of the reaction.

(*ii*) Show by calculation that **$KMnO_4$** is in excess.

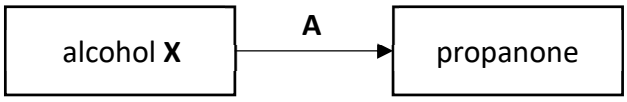
(*iii*) Calculate the mass of unreacted **$KMnO_4$** remaining in the reaction mixture.

(*iv*) Calculate the theoretical yield of benzoic acid.

(*v*) Calculate the percentage yield of benzoic acid. (25)

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

(*a*) The reaction scheme below shows the synthesis of propanone from alcohol **X**.



(*i*) Classify conversion **A** as an *addition*, *substitution or redox* reaction.

(*ii*) Identify a suitable reagent to bring about conversion **A**.

(*iii*) State the systematic IUPAC name for alcohol **X**.

(*iv*) Draw the structure of a molecule of alcohol **X** showing all of its atoms and all of its bonds. Clearly indicate on your diagram the bond(s) broken in alcohol **X** during conversion **A**.

(*v*) Draw the structure of a molecule of propanone showing all of its atoms and all of its bonds. Clearly indicate on your diagram the bond(s) formed in propanone during conversion **A**.

(*vi*) An isomer of propanone can be synthesised from a primary alcohol.
Identify both the isomer of propanone and the primary alcohol. (25)

(*b*) (*i*) Define oxidation in terms of electron transfer.

(*ii*) State the oxidation number of **Mn** in $\mathbf{MnO_4^-}$.

(*iii*) State the oxidation number of **C** in $\mathbf{C_2O_4^{2-}}$ and $\mathbf{CO_2}$.

(*iv*) Hence or otherwise, balance the following chemical equation:

$$\mathbf{MnO_4^- + H^+ + C_2O_4^{2-} \rightarrow Mn^{2+} + H_2O + CO_2}$$

(*v*) Identify the reducing agent in the reaction above. Justify your answer. (25)

(*c*)

acid	initial concentration	pH at 25 °C
HCl	0.1 M	1.0
CH_3COOH	0.1 M	2.8

(*i*) Explain what is meant by the term Brønsted-Lowry acid.

(*ii*) Write a balanced equation to show **CH_3COOH** acting as a Bronsted-Lowry acid in water.

(*iii*) Use the information provided to calculate K_a, the acid dissociation constant, of **CH_3COOH** at 25 °C.

The solution of **HCl** is diluted by a factor of 100.

(*iv*) Calculate the pH of the diluted **HCl** solution.

(*v*) Both acids have the same initial concentration. Explain, with reference to the hydrogen ion concentration, the difference in their pH values. (25)

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

A Carbon dioxide is a greenhouse gas. According to Ireland's Central Statistics Office, in 2023 Ireland had the second highest emissions in the EU with an average of 10.4 tonnes of carbon dioxide emitted for every person in the country.

(*i*) Explain what is meant by the term greenhouse gas.

(*ii*) State two major ways in which human activity contributes to the addition of carbon dioxide to the atmosphere.

Carbon dioxide is an acidic oxide. Acidic oxides can be removed from waste gases using scrubbers in chimneys.

(*iii*) Explain what is meant by the term acidic oxide.

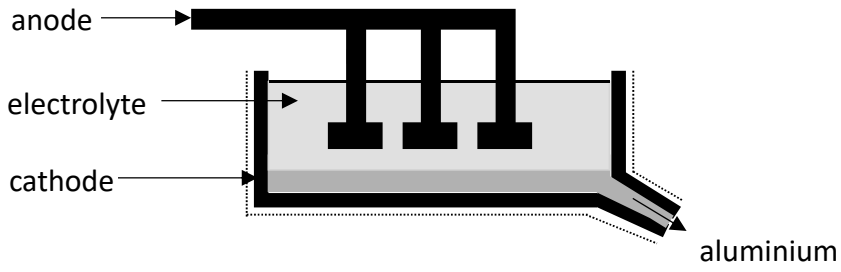
(*iv*) Describe how you would demonstrate, in a school laboratory, that carbon dioxide is an acidic oxide.

(*v*) Identify a reagent used in scrubbers to remove acidic oxides.

(*vi*) Identify three chemical species formed as a result of carbon dioxide gas dissolving in water. (25)

or

B Alumina ($\mathbf{Al_2O_3}$) can be processed into pure aluminium by electrolysis in an electrochemical cell similar to that shown in the diagram below.



(*i*) Name the ore from which alumina can be obtained.

(*ii*) Why must the $\mathbf{Al_2O_3}$ be molten or dissolved for the electrolysis stage?

(*iii*) Identify a suitable material for use as the anode.

(*iv*) Write a balanced chemical equation for the reaction that takes place at the anode.

(*v*) Identify a suitable material for use as the cathode.

(*vi*) Write a balanced chemical equation for the reaction that takes place at the cathode.

(25)

Images

Page 11 en.m.wikipedia.org/wiki/File:Bunsen-Kirchoff.jpg

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Leaving Certificate – Higher level

Chemistry

Tuesday, 16 June
Afternoon, 2:00 – 5:00