2027.M34S2

2027L022A1ES2

Coimisiún na Scrúduithe Stáit
State Examinations Commission

Leaving Certificate Examination
Sample 2

Chemistry

Higher Level

2 hours 30 minutes

300 marks

Examination Number

Date of Birth / /

For example, 3rd February 2005 is entered as 03 02 05

Centre Stamp

Instructions

There are seven questions on this paper. Each question carries 50 marks.

Answer **Question 1** and any **five other** questions.

Write your Examination Number and your Day, Month and Year of Birth in the boxes on the front cover.

Write your answers in blue or black pen. You may use pencil in graphs and diagrams only.

This examination booklet will be scanned and your work will be presented to an examiner on screen. All of your work should be presented in the answer areas, or on the given graphs, or diagrams. Anything that you write outside of these areas may not be seen by the examiner.

Write all answers into this booklet. There is space for extra work at the back of the booklet. If you need to use it, label any extra work clearly with the question number and part.

The superintendent will give you a copy of the *Formulae and Tables* booklet. You must return it at the end of the examination. You are not allowed to bring your own copy into the examination.

Data from the *Formulae and Tables* booklet, including atomic numbers and relative atomic masses, should be used wherever necessary.

You may lose marks if your solutions do not include relevant supporting work.

You may lose marks if the appropriate units of measurement are not included, where relevant.

You may lose marks if your answers are not given in their simplest form, where relevant.

Diagrams are generally not drawn to scale.

Write the make and model of your calculator(s) here: | |

Question 1

(a) The nature of chemical bonding is on a continuum from ionic bonding, through polar covalent bonding, to pure covalent bonding.

Atoms of beryllium (Be) and fluorine (F) bond together to form the compound beryllium fluoride.

(i) By reference to data on page 81 of the *Formulae and Tables* booklet, predict the nature of the chemical bonding in beryllium fluoride.

(ii) Predict the chemical formula of beryllium fluoride.

(iii) Explain why the arrangement of electrons in beryllium fluoride does not satisfy the "octet rule".

(b) The enthalpy change (ΔH) for a chemical reaction can be calculated using bond enthalpy data for the bonds in the reactants and products.

(i) Explain what is meant by the term 'bond enthalpy'.

The combustion of methane can be described by the following balanced chemical equation:

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

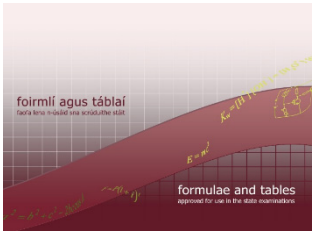
The reactants and products are all gases.

(ii) Use the bond enthalpy data in the table below to calculate ΔH for this reaction.

bond	bond enthalpy (kJ mol^{-1})
C – H	413
O = O	498
O – H	464
C = O	805

(c) Describe the significance of the carbon cycle in relation to both the natural and the human-influenced greenhouse effect.
Use words and/or diagrams.

(d) The following data for the element boron (B) may be found on page 83 of the *Formulae and Tables* booklet.



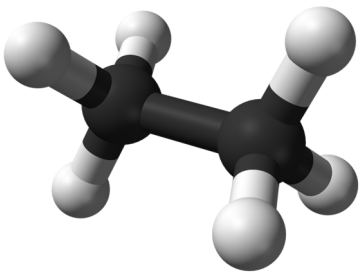
Z	symbol	mass of atom (u)	abundance (%)
5	^{10}B	10.012 937	19.9
	^{11}B	11.009 305	80.1

(i) How many neutrons are in an atom of ^{10}B?

(ii) Calculate the relative atomic mass of boron.

(iii) Explain why the mass of an atom of ^{10}B is not a whole number when expressed in atomic mass units (u).

(e) A molecule of ethane is shown in the diagram on the right.



Ethane reacts with chlorine gas (Cl_2) in a free radical substitution reaction.

(i) Describe the initiation step for this reaction.

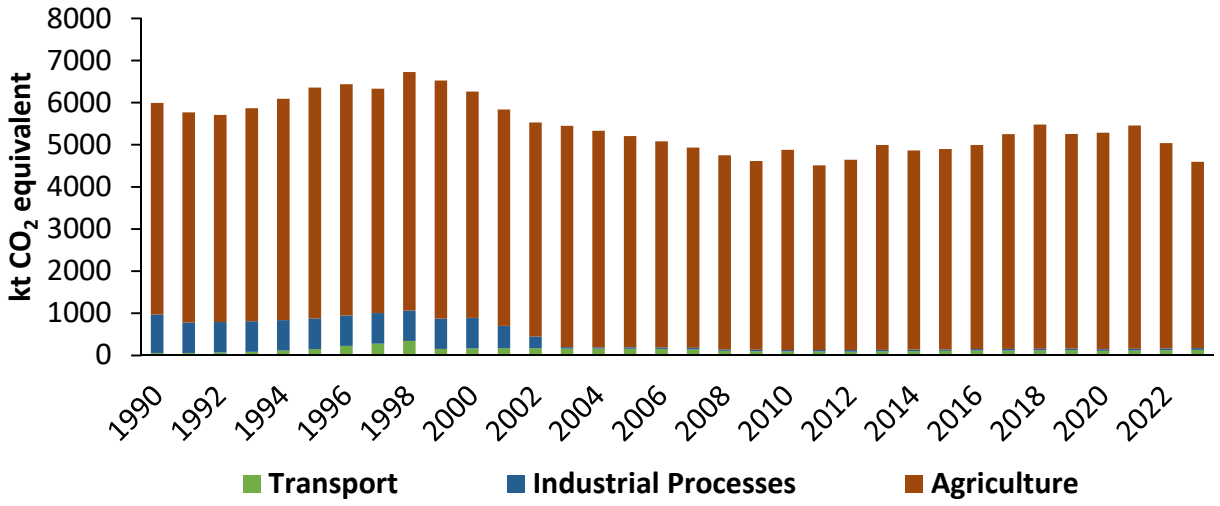
(ii) Describe the propagation steps for this reaction.

Several possible termination steps can take place for this reaction.

(iii) Identify the hydrocarbon compound that could be produced during one of these termination steps.

Question 2

(a) Nitrous oxide (N_2O) is a major contributor to global warming. Data from the Environmental Protection Agency (EPA) shows Ireland's N_2O emissions from three different economic sectors, between 1990 and 2023.



The industrial production of nitric acid (HNO_3) contributes to the emission of N_2O.

(i) Using information from the graph, suggest the year that Ireland closed its nitric acid production plant.

(ii) Suggest a reason why the EPA should be considered a reliable source of information.

(iii) Calculate the oxidation number of nitrogen in N_2O.

(iv) Calculate the oxidation number of nitrogen in HNO_3.

(b) Nitric acid may be used to produce calcium ammonium nitrate ($5Ca(NO_3)_2 \cdot NH_4NO_3 \cdot 10H_2O$).

This compound is used as a fertiliser and is commonly known as CAN.

When dissolved in water, CAN dissociates into the calcium ion (Ca^{2+}), the ammonium ion (NH_4^+), and the nitrate ion (NO_3^-).

(i) Write the arrangement of electrons in energy levels and sublevels for the Ca^{2+} ion.

(ii) Calculate the percentage by mass of nitrogen in calcium ammonium nitrate.

Ammonium ions (NH_4^+) react with water to produce ammonia (NH_3).

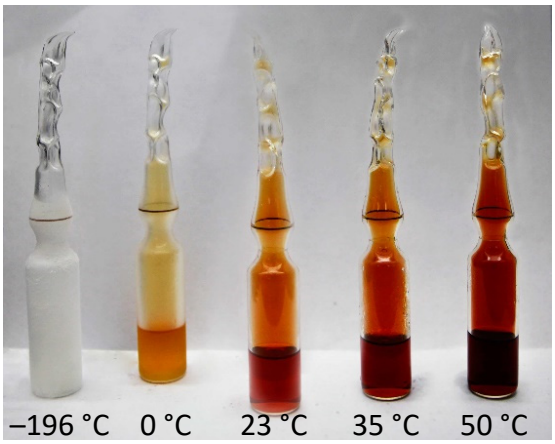
(iii) Do the ammonium ions act as an acid or a base when they react with water as described? Justify your answer.

(iv) Describe a chemical test to show that CAN contains nitrate (NO_3^-) ions.
Your description should identify the reagent(s) used and the observation(s) that indicate the presence of nitrate ions.

(c) Another oxide of nitrogen is nitrogen dioxide (NO_2), a brown compound which forms an equilibrium mixture with colourless dinitrogen tetroxide (N_2O_4), as described by the following balanced chemical equation:

$$\underset{\text{brown}}{2NO_2} \rightleftharpoons \underset{\text{colourless}}{N_2O_4}$$

The photograph on the right shows the equilibrium mixture at five different temperatures.



(i) Is the conversion of NO_2 to N_2O_4 (the forward reaction) exothermic or endothermic?
Justify your answer.

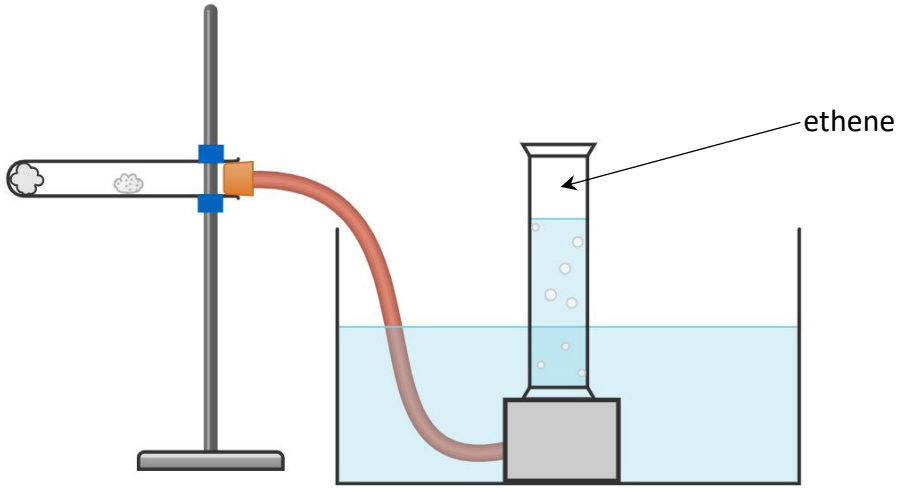
K_c = 0.5 for this reaction at temperature *T*.

When 2 moles of pure NO_2 and 1 mole of pure N_2O_4 were sealed in a 1 litre vessel, a reaction occurred and an equilibrium was established at temperature *T*.

(ii) Calculate the number of moles of each gas present when the reaction is at equilibrium.

Question 3

(a) A student prepared a sample of ethene gas in the laboratory. The diagram below shows part of the setup of the apparatus the student used. Note that one essential piece of apparatus is missing from the diagram.



(i) On the diagram above, use labels to identify each of the chemical compounds used in the preparation of ethene.
Your labels should show where each of these compounds is held.

(ii) Draw the essential piece of missing apparatus in the appropriate place on the diagram.

When preparing ethene, the student was advised to prevent suck-back**.**

(iii) Explain what is meant by the term 'suck-back'.

(iv) Explain how the student could have prevented suck-back from happening.

(v) Other than precautions to prevent suck-back, describe and explain one other specific safety precaution which the student should have taken.

The student burned a sample of the ethene prepared. However, there was insufficient oxygen present for complete combustion, i.e. the ethene underwent partial combustion.

(vi) What observation would indicate that there was insufficient oxygen present?

(vii) Write a balanced chemical equation for the complete combustion of ethene.

(b) Molecules of ethene can undergo addition reactions with other molecules of ethene to form a polymer.

(i) Name the polymer produced by the polymerisation of ethene.

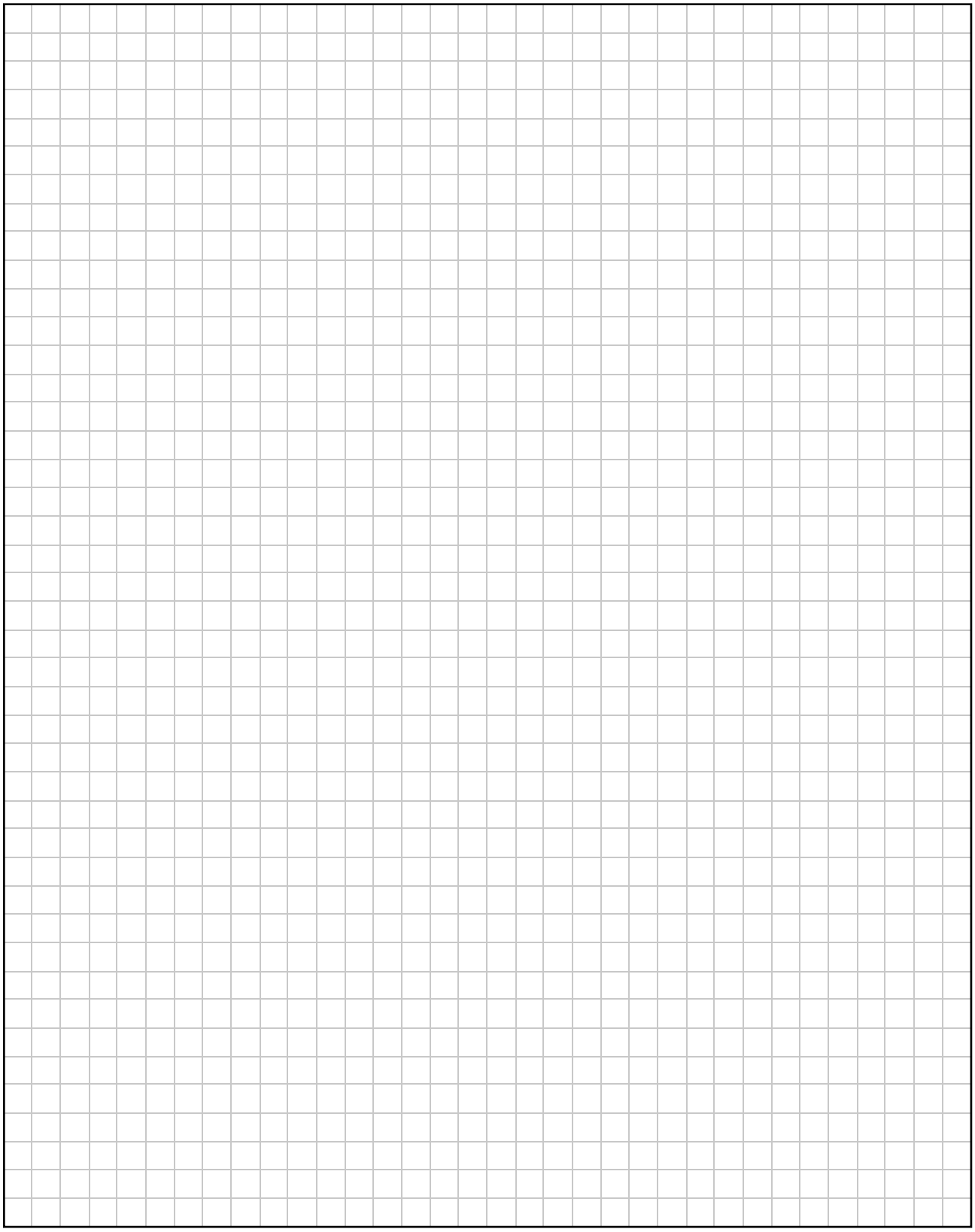
(ii) Draw three repeating units of this polymer.

This polymer is non-biodegradable.

(iii) Describe how its non-biodegradability is related to the polymer's chemical properties.

(c) There are a number of alkenes with the molecular formula C_4H_8.

Draw the molecular structure of four alkene isomers with the molecular formula C_4H_8, including all atoms and bonds.
Under each of the structures you have drawn, state the IUPAC name for that isomer.



Question 4

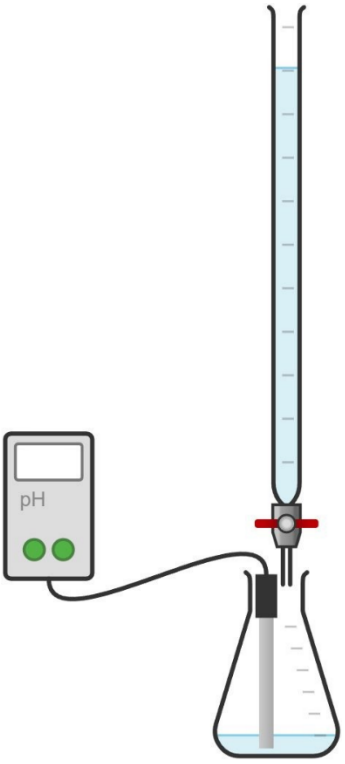
A student carried out an experiment to investigate the concentration of ethanoic acid in a bottle of vinegar.

A 25.0 cm^3 portion of the vinegar was diluted to exactly 100.0 cm^3.

The diluted vinegar solution was used to fill the burette.

The student dissolved 1.8 g of sodium hydroxide (NaOH) in enough water to make 500.0 cm^3 of solution. 25.0 cm^3 of this solution was placed in a conical flask.

The titration reaction was monitored using a pH meter.

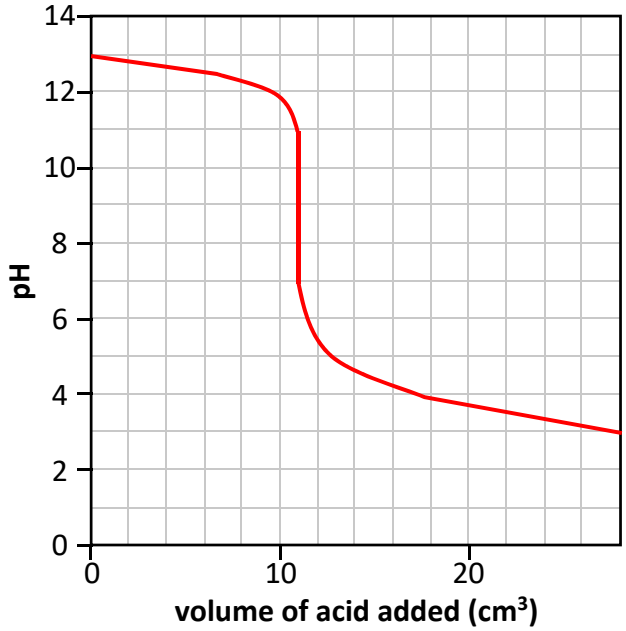


(i) Describe the procedure for preparing the burette and then filling it with the diluted vinegar solution.

Before the reaction was started, the probe of the pH meter was placed into a buffer solution.

(ii) Explain the purpose of using a buffer solution.

The data collected during the titration are plotted on the graph on the right.



(iii) Which of the following types of titration is represented by the graph?
Place a tick (✓) in the correct box.

strong acid – strong base ☐

strong acid – weak base ☐

weak acid – strong base ☐

redox ☐

(iv) Justify your choice in part **(iii)** by reference to the graph.

(v) Which of the following indicators would be most suitable for this titration?
Place a tick (✓) in the correct box.

methyl orange (pH range 3.1 – 4.4) ☐

bromothymol blue (pH range 6.0 – 7.6) ☐

o-cresolphthalein (pH range 8.2 – 9.8) ☐

indigo carmine (pH range 11.4 – 13.0) ☐

(vi) Justify your choice in part **(v)** by reference to the graph.

The student titrated the diluted vinegar solution against 25.0 cm^3 portions of the NaOH solution. The reaction is described by the following balanced chemical equation:

$$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$$

The student carried out one approximate titration and two accurate titrations.
In the table below, the student recorded the volume of the diluted vinegar solution that was needed to neutralise the sodium hydroxide.

titration	approximate	accurate 1	accurate 2
volume (cm^3)	11.1	10.9	10.8

(vii) Calculate the number of moles of sodium hydroxide in a 25.0 cm^3 portion of this sodium hydroxide solution (1.8 g of NaOH in 500.0 cm^3).

(viii) Calculate the number of moles of ethanoic acid in each cm^3 of the diluted vinegar solution.

(ix) Calculate the concentration of ethanoic acid in the undiluted vinegar in moles per litre.

(x) Calculate the concentration of ethanoic acid in the undiluted vinegar in % w/v.

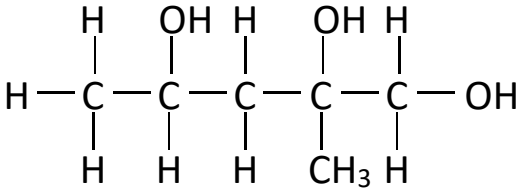
(xi) The NaOH solution used in this titration should have been standardised before it was used. What is meant by standardisation?

Ethanoic acid is an example of a carboxylic acid.

(xii) Explain how the inductive effect in ethanoic acid and resonance in the ethanoate ion affects the acidic nature of ethanoic acid.
Your answer should include diagrams showing the distribution of charge in both ethanoic acid and the ethanoate ion.

Question 5

(a) The molecular structure shown below has three alcohol groups. One is a primary alcohol group, one is a secondary alcohol group and one is a tertiary alcohol group.



Write the number 1 next to the primary alcohol group.

Write the number 2 next to the secondary alcohol group.

Write the number 3 next to the tertiary alcohol group.

(b) In the presence of a solution of acidified potassium permanganate ($H^+/KMnO_4$), some alcohols can be oxidised to form compounds that have other functional groups.

(i) Name the type(s) of organic compounds, if any, which can be formed by the oxidation of primary alcohols under the conditions described.

(ii) Name the type(s) of organic compounds, if any, which can be formed by the oxidation of secondary alcohols under the conditions described.

(iii) Name the type(s) of organic compounds, if any, which can be formed by the oxidation of tertiary alcohols under the conditions described.

(c) The oxidation of alcohols as described in part **(b)** may be reversed using a suitable reducing agent and catalyst.

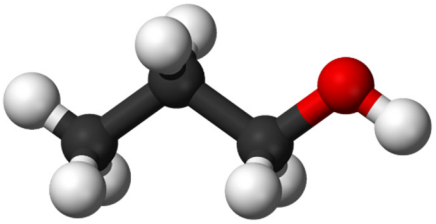
(i) Identify a suitable reducing agent.

(ii) Identify a suitable catalyst.

This catalysis may be described by the surface adsorption mechanism.

(iii) Describe how the surface adsorption mechanism can explain how some catalysts work.

(d) A molecule of propan-1-ol is shown in the diagram.



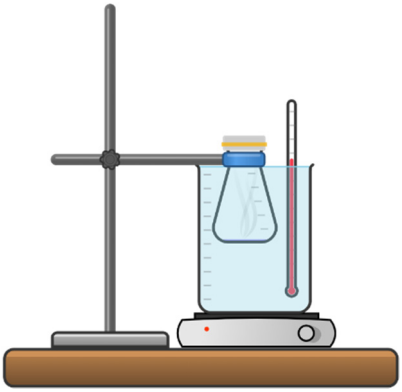
(i) Explain, using a chemical equation or otherwise, how propan-1-ol can react as an acid.

When propan-1-ol reacts with methanoic acid under reflux conditions, the ester propyl methanoate is produced.

(ii) Draw the molecular structure of propyl methanoate, including all atoms and bonds.

(iii) State the IUPAC name of two other esters which are structural isomers of propyl methanoate.

(e) A sample of propan-1-ol was placed in a conical flask and heated in a water bath so that it became a gas, as shown in the diagram.



There was a small hole in the lid of the flask to allow some of the gas to escape and so that it was at atmospheric pressure, 1.013×10^5 Pa.

The propan-1-ol occupied a volume of 77.0 cm^3 at a temperature of 100.0 °C.

Calculate the mass of propan-1-ol vapour in the flask.

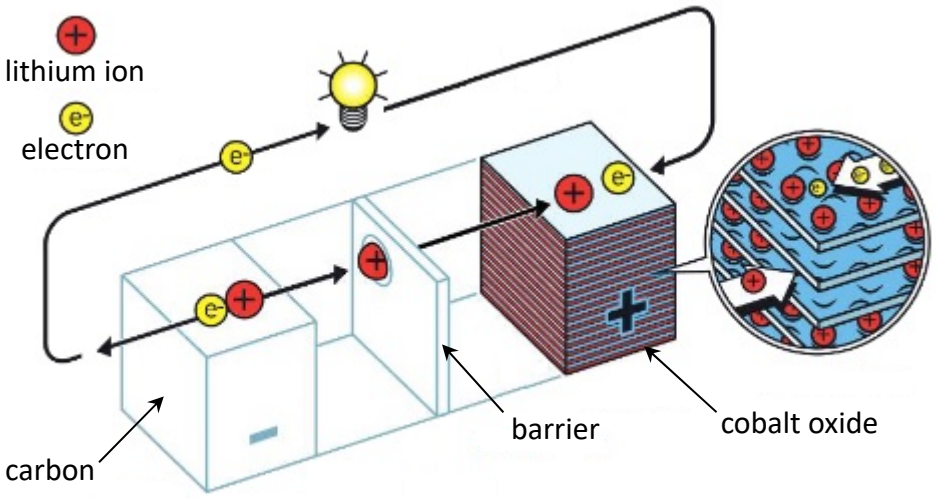
Question 6

(a) In 2019 the Royal Swedish Academy of Sciences awarded the Nobel Prize in Chemistry to John B. Goodenough, M. Stanley Whittingham and Akira Yoshino for their contributions to the development of the lithium-ion battery. The Academy noted that lithium-ion batteries have "laid the foundation of a wireless, fossil fuel-free society, and are of the greatest benefit to humankind".

A lithium-ion battery contains a number of lithium-ion cells, which are classified as secondary cells.

(i) What is a secondary cell?

In one common type of lithium-ion cell, a certain allotrope of carbon is used in one electrode and cobalt oxide is used in the other electrode, as shown in the diagram.



When a cell of this type acts as a galvanic cell, the overall reaction in the cell may be described by the following balanced chemical equation:

$$LiC_6 + CoO_2 \rightarrow C_6 + LiCoO_2$$

(ii) Name the allotrope of carbon used in one of the electrodes.

(iii) What is a galvanic cell?

(iv) The diagram shows a barrier in the cell. Explain the function of the barrier.

(v) Write the oxidation half-reaction that takes place when a lithium-ion cell of this type acts as a galvanic cell.

(vi) Write the reduction half-reaction that takes place when a lithium-ion cell of this type acts as a galvanic cell.

Lithium reacts with water to produce lithium hydroxide and hydrogen gas. Because of this, the electrolyte used in lithium-ion cells does not contain water. Organic solvents are used instead.

(vii) Write a balanced chemical equation for the reaction between lithium and water.

(viii) Explain the function of the electrolyte.

(ix) Describe one impact which lithium-ion technology has on our environment.

(b) A student synthesised benzoic acid (C_6H_5COOH) in the laboratory by oxidising 4.5 cm^3 of phenylmethanol ($C_6H_5CH_2OH$). The student used an excess of potassium permanganate ($KMnO_4$) as the oxidising agent, under basic conditions.

(i) Identify a base that is suitable to use in this experiment.

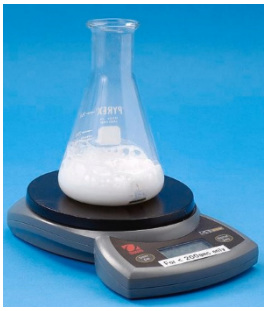
(ii) Describe the colour changes observed during the reaction as the manganese in $KMnO_4$ is reduced from Mn^{7+} to Mn^{4+} and then to Mn^{2+}.

The student obtained 3.6 g of pure benzoic acid at the end of the experiment.

(iii) How could the student have confirmed that the benzoic acid was pure?

(iv) Calculate the percentage yield. (Phenylmethanol has a density of 1.04 g cm^{-3}. Note that each molecule of phenylmethanol produces one molecule of benzoic acid.)

Question 7



During an investigation of factors that affect the rate of a chemical reaction, a student placed a conical flask on a mass balance and set it to record a mass of 0.00 g. The student then added 50.0 cm^3 of a 1.5 M solution of hydrochloric acid (HCl) to the flask. The student added 3.00 g of solid anhydrous lithium carbonate (Li_2CO_3) and immediately started a stop-watch. As the reaction proceeded, the student recorded the mass of the contents in the flask, which decreased over time.

The reaction that occurred is described by the following balanced chemical equation:

$$Li_2CO_3 + 2HCl \rightarrow 2LiCl + H_2O + CO_2$$

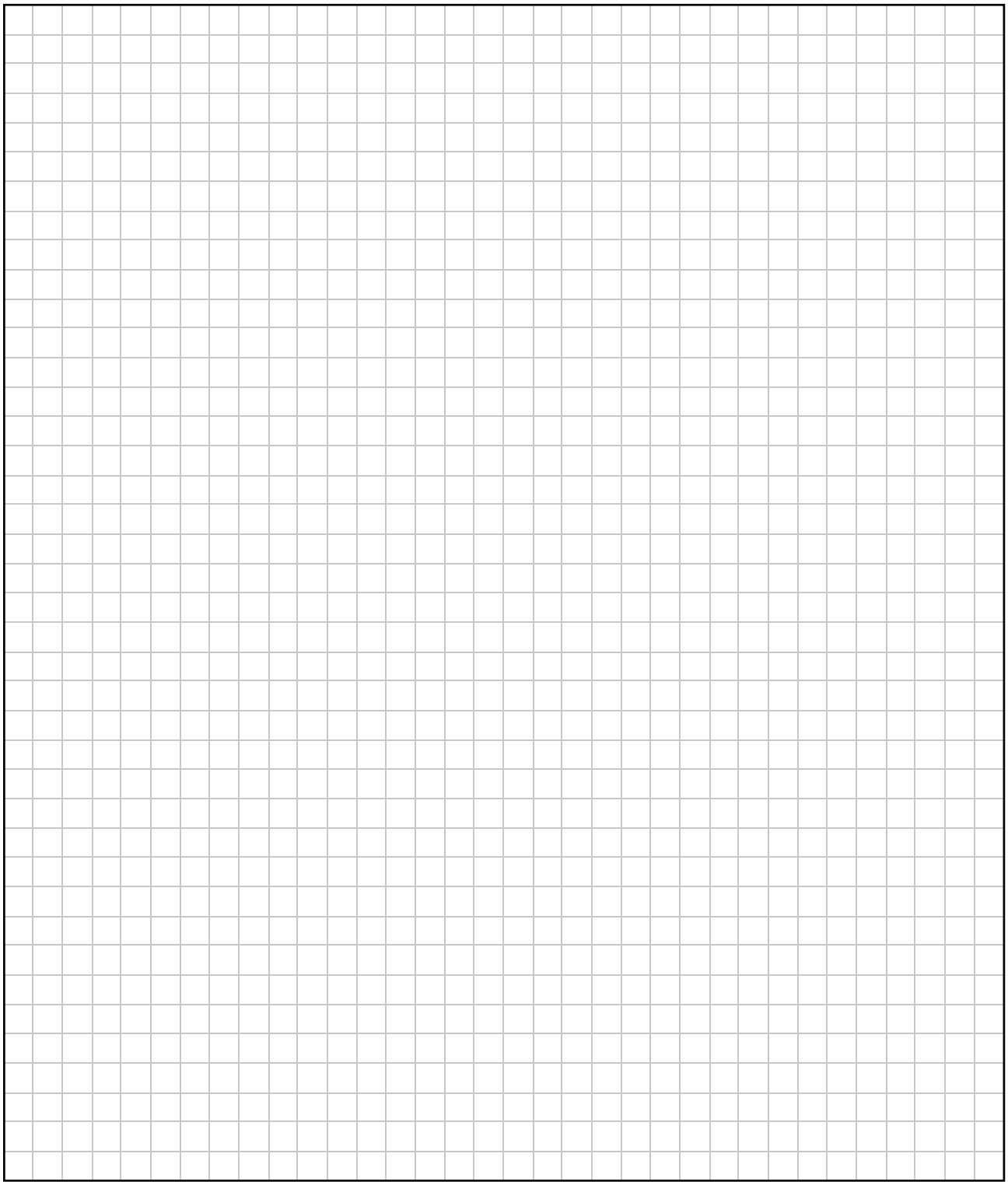
(i) Explain why the mass of the contents in the flask decreased over time.

(ii) Determine, by calculation, which reactant is in excess.

The student recorded the mass of the contents in the conical flask over time until the mass was constant. The student's results are shown in the table below.

time (s)	0	10	20	30	40	50	60	70	80	90
mass (g)	56.00	55.32	54.92	54.71	54.58	54.47	54.40	54.36	54.35	54.35

(iii) Plot a graph of mass against time. The axis for mass should begin at 54 g.



(iv) Calculate the initial rate of this reaction.

(v) On your graph, sketch the curve that you would obtain if the reaction had taken place at a higher temperature.

(vi) Use the recorded results to calculate the density of the of hydrochloric acid.
(Note that the initial mass of 56.00 g was recorded *after* the 3.00 g of Li_2CO_3 were added.)

The student noticed that the temperature of the solution increased slightly during this reaction.

(vii) Is this reaction endothermic or exothermic?

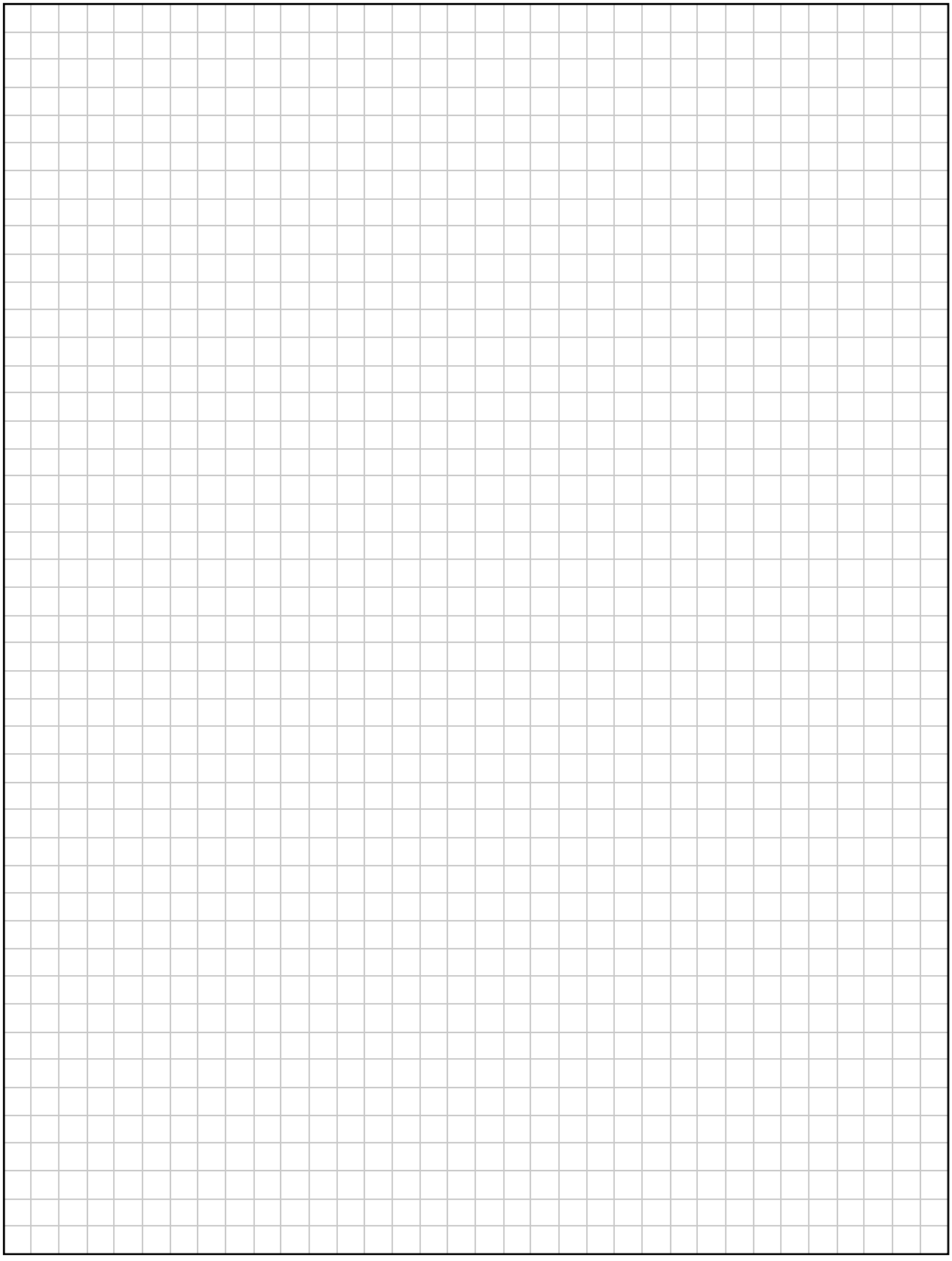
(viii) Complete the reaction profile diagram for this reaction.

(ix) A student carried out a flame test to check that the solid used in this investigation contained lithium ions. What colour flame would the student have observed?

(x) Describe how the student could test to check that the solid used in this investigation contained carbonate ions, rather than hydrogencarbonate ions.
Your description should identify the reagent(s) used and the observation(s) that indicate the presence of carbonate ions.

Page for extra work.

Label any extra work clearly with the question number and part.



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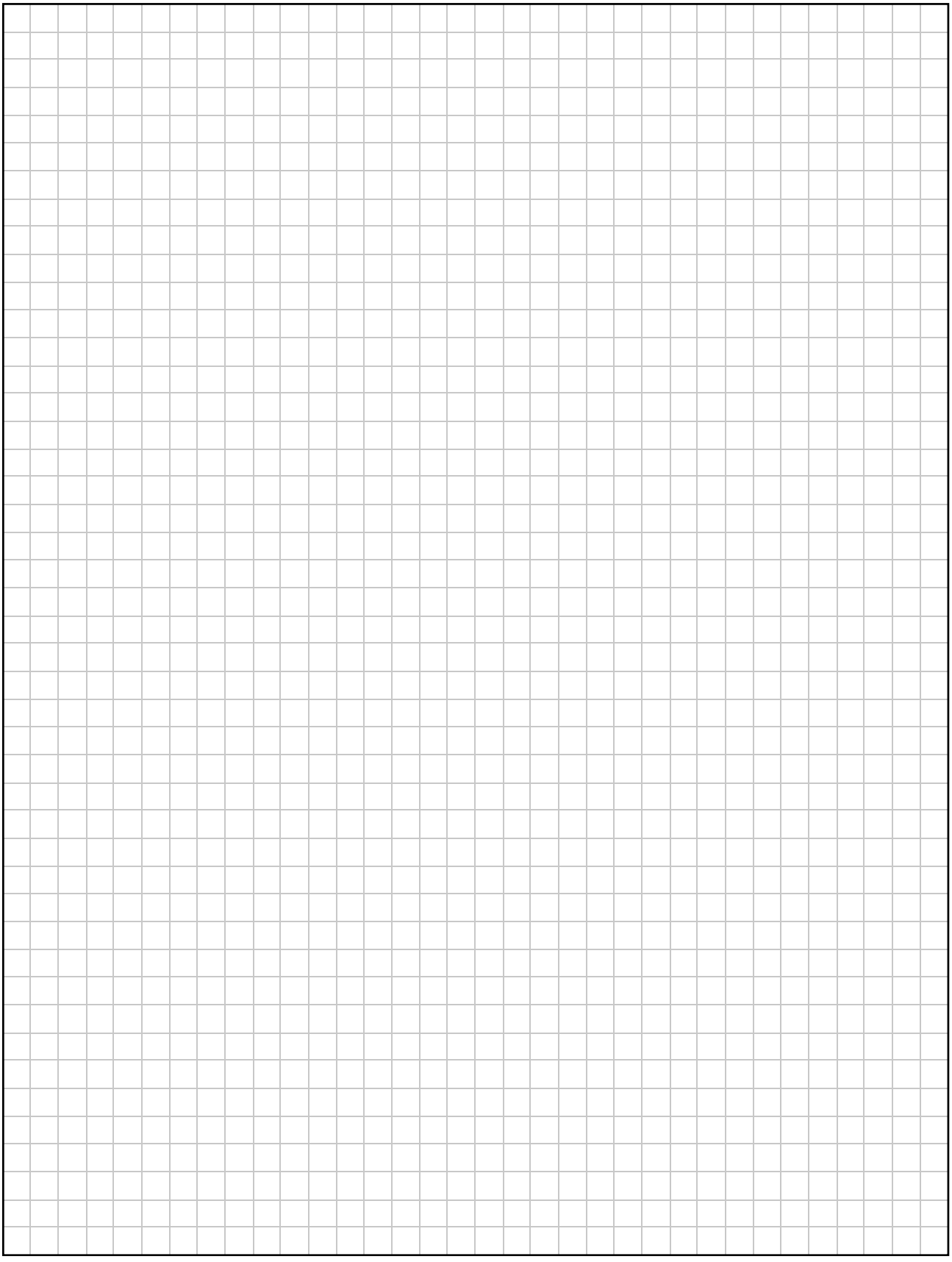

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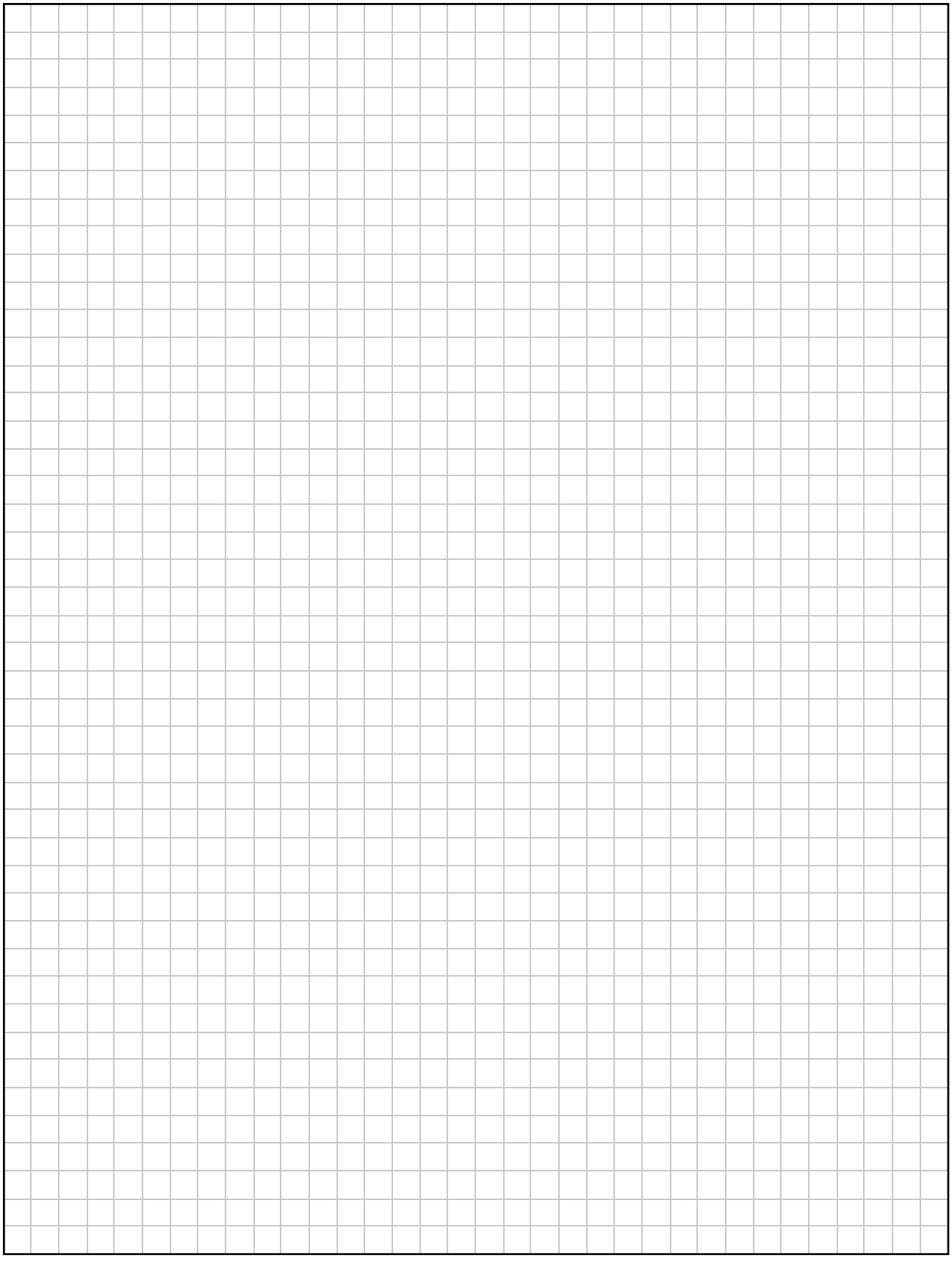

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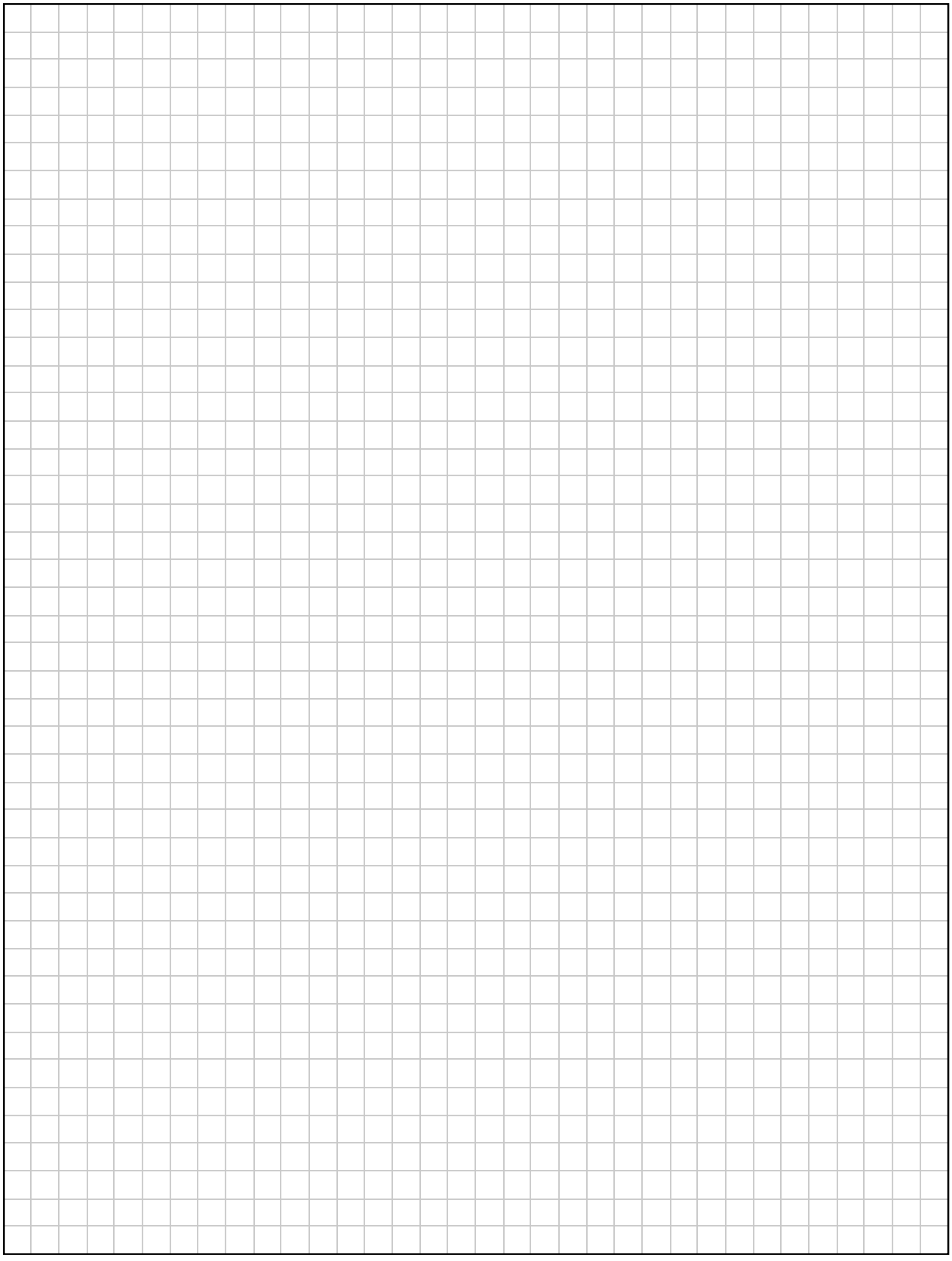

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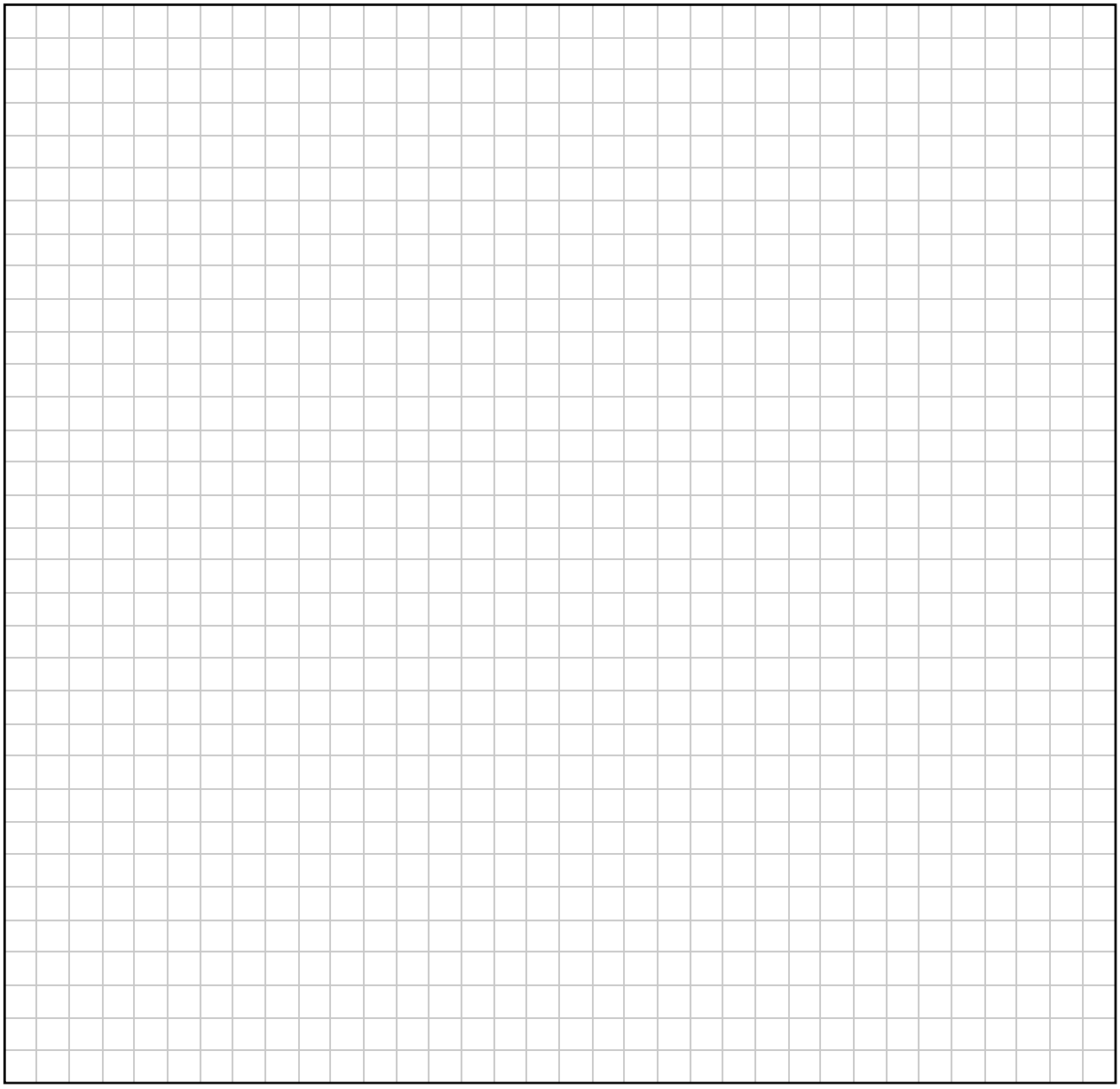

Acknowledgements

Images

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Leaving Certificate Examination – Higher Level

Chemistry

Sample 2

2 hours 30 minutes