Question 1

3. The reaction of sodium thiosulfate with hydrochloric acid is described by the following balanced chemical equation:

$$\mathbf{Na_2S_2O_3 + 2HCl \rightarrow 2NaCl + SO_2 + S + H_2O}$$

To investigate the effect of *concentration* on the rate of this reaction, the experiment was carried out for a number of different concentrations of sodium thiosulfate solution. For each run, a stopwatch was started when 100 cm^3 of $\mathbf{Na_2S_2O_3}$ were mixed with 10 cm^3 of 3 M **HCl**.

For each run, the reaction was carried out at room temperature and the time taken for the same mass of sulfur to precipitate was measured. The inverse of that time was taken as a measure of the initial rate of reaction.

The results are shown in the table below.

Concentration of $\mathbf{Na_2S_2O_3}$ (M)	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.03
Time (s)	50	56	63	72	84	100	125	168
Rate = $\frac{1}{\text{Time}}$ (s^{-1})	0.020	0.018						

(*a*) (*i*) Describe a method that could be used to know when the same mass of sulfur had been precipitated in each run.

(*ii*) Describe how a 0.10 M solution of $\mathbf{Na_2S_2O_3}$ could be used to prepare a 100 cm^3 portion of 0.09 M $\mathbf{Na_2S_2O_3}$ solution. (12)

(*b*) (*i*) Copy and complete the third row of the table into your answerbook by filling in the missing rate values, correct to three decimal places.

(*ii*) Draw a graph on graph paper to show how the rate of the reaction varies with the concentration of sodium thiosulfate solution.

(*iii*) What can be concluded from your graph? (20)

(*c*) (*i*) Use your graph to estimate the rate of reaction if 100 cm^3 of 0.015 M $\mathbf{Na_2S_2O_3}$ solution had been used.

(*ii*) Calculate the time taken for the sulfur to precipitate in this case. (8)

(*d*) To investigate the effect of *temperature* on the rate of this reaction, the time taken for the same mass of sulfur to precipitate was measured at three different temperatures, using fixed volumes and concentrations of the reactants.

The results are shown in the table below.

Temperature (°C)	T_1	T_2	T_3
Time (s)	40	10	25

(*i*) Describe a suitable method for heating the reactants and measuring the reaction temperature. A labelled diagram may help your answer.

(*ii*) Which temperature (T_1, T_2 or T_3) was the highest? Justify your answer. (10)

Question 2

1. A student carried out an experiment to determine the iron(II) content of an iron supplement tablet. Six iron tablets with a total mass of 2.496 g were dissolved in dilute sulfuric acid. The solution and the washings were transferred to a 250 cm^3 volumetric flask and made up to the mark using deionised water. A 25.0 cm^3 portion of this solution was transferred into a conical flask and some sulfuric acid was added. The solution was then titrated against a previously standardised solution of potassium manganate(VII) (**$KMnO_4$**). A number of titrations were carried out.

The titration reaction is described by the following balanced equation:

$$MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$$

(*a*) Identify a primary standard that the student could have used to standardise the solution of potassium manganate(VII). (5)

(*b*) (*i*) Outline the correct procedure for bringing the solution in the volumetric flask precisely to the 250 cm^3 mark.

(*ii*) Explain why using more than one iron tablet in the 250 cm^3 of solution increases the accuracy of the analysis. (9)

(*c*) (*i*) Name the piece of apparatus used to accurately measure and transfer the 25.0 cm^3 portion of iron(II) solution into the conical flask.

(*ii*) Describe how this piece of apparatus was rinsed before use. (9)

(*d*) (*i*) Explain why the addition of an indicator into the conical flask was not required.

(*ii*) Describe what the student observed at the end point.

(*iii*) Describe what would be observed in the conical flask if insufficient acid was present during the titration. Explain your answer. (12)

(*e*) On average, 22.5 cm^3 of 0.010 M potassium manganate(VII) solution were required for complete reaction with 25.0 cm^3 of the solution of the iron(II) in excess acid.

(*i*) Calculate the number of moles of manganate(VII) ions present in 22.5 cm^3 of 0.010 M potassium manganate(VII) solution.

(*ii*) Calculate the number of moles of iron(II) present in the 250 cm^3 solution in the volumetric flask.

(*iii*) Calculate the average mass of iron(II) in one tablet.

(*iv*) Calculate the percentage by mass of iron(II) in one tablet. (15)

Question 3

1. A student carried out an experiment to determine the concentration of ethanoic acid in vinegar. A 10.0 cm^3 portion of the vinegar was first diluted to exactly 50.0 cm^3. The diluted vinegar solution was titrated against a 0.09 M sodium hydroxide solution in a conical flask. On average, 12.4 cm^3 of the *diluted* vinegar were required to neutralise 25.0 cm^3 of the **NaOH** solution.

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

$$\mathbf{CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O}$$

(*a*) (*i*) Name the piece of apparatus used to measure accurately the 10.0 cm^3 portion of the original vinegar.

(*ii*) Describe how this piece of apparatus was rinsed before use.

(*iii*) Describe a suitable method to dilute the 10.0 cm^3 portion of the original vinegar to exactly 50.0 cm^3. (15)

(*b*) (*i*) Calculate the volume of *undiluted* vinegar which would be required to neutralise 25.0 cm^3 of the 0.09 M **NaOH** solution.

(*ii*) Outline an advantage of diluting the vinegar before carrying out the titration. (9)

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

(*ii*) State the colour change observed at the end point. (9)

(*d*) (*i*) Calculate the number of moles of sodium hydroxide in each 25.0 cm^3 portion.

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

(*iii*) Calculate the concentration of ethanoic acid in the original vinegar in moles per litre.

(*iv*) Calculate the concentration of ethanoic acid in the original vinegar in % (w/v). (17)

Question 4

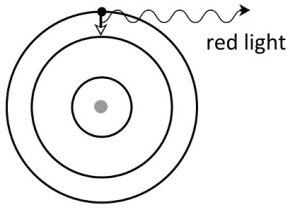
Section B

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*) The set of elements {**Li**, **Na**, **K**} is one of Dobereiner's triads. Refer to this example to explain Dobereiner's contribution to the development of the periodic table.

(*b*) The diagram shows the origin of one of the lines in the Balmer series of the hydrogen emission spectrum. Why is a photon emitted as the electron moves from one energy level to another as shown?



(*c*) Why is the second ionisation energy of lithium significantly larger than its first?

(*d*) What colour is observed in a flame test on a salt of
(*i*) lithium,
(*ii*) copper?

(*e*) State Avogadro's law.

(*f*) One of the largest diamonds ever mined was found in Botswana in June 2021. The diamond had a mass of 1098 carats and contained exactly 18.3 moles of carbon. Assuming this stone contained only carbon, calculate the mass of one carat expressed in grams.

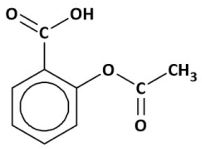
(*g*) What reagents are used to confirm the presence of nitrate ions in an aqueous solution?

(*h*) Identify a substance commonly added during drinking water treatment
(*i*) to cause flocculation in the water,
(*ii*) to fluoridate the water.

(*i*) What elements are the products of the electrolysis of an aqueous solution of potassium iodide (**KI**) using inert electrodes?

(*j*) Which one of the following four compounds would you expect to have the strongest carbon to carbon bonding: ethane, ethene, ethyne, benzene?

(*k*) The structure of aspirin is shown. Calculate the average daily dose (in mg) when a person took a total of 0.146 moles of 'low dose' aspirin over 365 days.



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

A Write balanced equations to show the dissociation of carbonic acid in water to form first hydrogencarbonate ions and then carbonate ions.

or

B Iodine ($\mathbf{I_2}$) is an example of a molecular crystal.
What distinguishes molecular crystals from other types of crystals?

Question 5

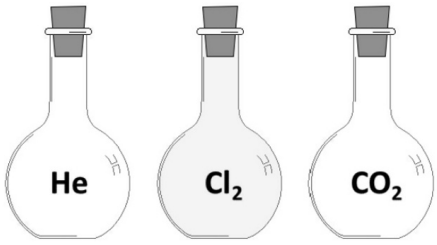
4. Answer **eight** of the following (*a*), (*b*), (*c*), etc. (50)

(*a*) How many (*i*) electrons, (*ii*) neutrons, does a $^{32}_{16}\mathbf{S}^{2-}$ ion have?

(*b*) Define an atomic orbital.

(*c*) Write the *s*, *p*, *d* electron configuration for a nickel atom in the ground state.

(*d*) The diagram shows three containers, each filled with a different gas. Each container holds the same volume of gas at the same temperature and pressure.
Which contains the largest number of atoms? Explain.



(*e*) Define electronegativity.

(*f*) Take the average bond energies for the **C—C** single bond and the **C≡C** triple bond as 348 and 839 kJ mol^{-1} respectively.
Why is the average bond energy for the **C≡C** triple bond less than three times the average bond energy for the **C—C** single bond?

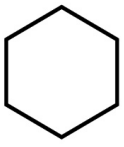
(*g*) Two volumes of an oxide of nitrogen decomposed in the presence of a heated catalyst to form two volumes of nitrogen gas and one volume of oxygen gas, all volumes measured at the same conditions of temperature and pressure.
Use this information to deduce the formula of the oxide of nitrogen that decomposed.

(*h*) The use of **$KBrO_x$** as a flour additive has been banned in the EU for many years but it is sometimes used to bleach flour and strengthen dough in some jurisdictions.
$KBrO_x$ contains 47.9% bromine by mass.
Find the value of ***x***.

(*i*) Show by means of an equilibrium equation the self-ionisation of water that occurs even in 'deionised' water.

(*j*) Give a use that propanoic acid, benzoic acid and the salts of these acids have in common.

(*k*) What is the average number of electrons shared between any two adjacent carbon atoms in a molecule of
(*i*) cyclohexane,
(*ii*) benzene?


cyclohexane


benzene

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

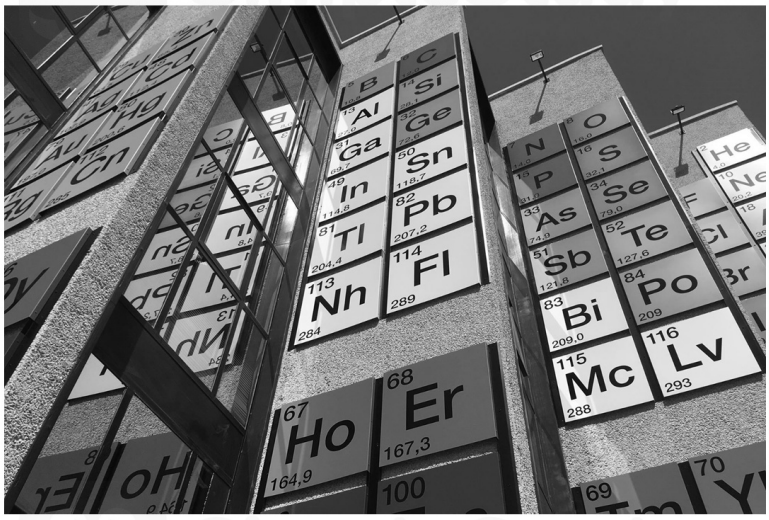
A Give one advantage *and* one disadvantage of using a batch process in the chemical industry.

or

B What is the structural difference between LDPE or low-density poly(ethene) and HDPE or high-density poly(ethene)?

Question 6

5. To celebrate the 150th anniversary of the discovery of the periodic system, 2019 has been designated as the International Year of the Periodic Table of Chemical Elements by the United Nations (UN).



(*a*) (*i*) What is meant by the *periodic system* in the context of Mendeleev's 1869 periodic table of the elements?

(*ii*) Comment on the positioning of tellurium (**Te**) and iodine (**I**) in the 1869 table.

(*iii*) Why did the 1869 table not include any noble gases? (11)

(*b*) Modern periodic tables arrange the elements in order of atomic number and not in order of relative atomic mass.

(*i*) Define the underlined terms.

(*ii*) Give an advantage of arranging the elements in order of atomic number. (12)

(*c*) Explain

(*i*) why all the elements of Group 18 in the periodic table are chemically inert,

(*ii*) how *and* why the reactivity of the halogens changes down Group 17. (12)

(*d*) The element francium (**Fr**), atomic number 87, was discovered by Marguerite Perey in 1939 but its physical and chemical properties had already been predicted by the periodic system.

(*i*) How would you expect a small sample of francium to react in water? Justify your answer.

(*ii*) Predict the products of this reaction. (15)

Question 7

(*b*) Succinic acid and its salts are food additives. The formula of a molecule of succinic acid is $\mathbf{(CH_2)_n(COOH)_2}$ where $\boldsymbol{n} > 1$. Succinic acid reacts with sodium hydroxide according to the following balanced equation:

$$\mathbf{(CH_2)_n(COOH)_2 + 2NaOH \rightarrow (CH_2)_n(COONa)_2 + 2H_2O}$$

When 1.77 g of succinic acid react completely with sodium hydroxide 2.43 g of $\mathbf{(CH_2)_n(COONa)_2}$ (disodium succinate) are formed.

(*i*) Write expressions in terms of $\boldsymbol{n}$ for the molar masses of $\mathbf{(CH_2)_n(COOH)_2}$ and $\mathbf{(CH_2)_n(COONa)_2}$.

(*ii*) Write expressions in terms of $\boldsymbol{n}$ for the number of moles of succinic acid in 1.77 g of the acid and the number of moles of disodium succinate in 2.43 g of the salt.

(*iii*) Find the value of $\boldsymbol{n}$ and the mass of one mole of succinic acid.

(*iv*) What volume of a 0.12 M **NaOH** solution is required for complete reaction with an aqueous solution containing 1.77 g succinic acid? (25)

Question 8

(*c*) A molecule of pharmaceutical **X** contains atoms of carbon, hydrogen, nitrogen, oxygen and sulfur, only. When **X** is burned in excess oxygen the only products are water, carbon dioxide, $\mathbf{SO_2}$ and $\mathbf{NO_2}$.
When a sample of **X** was completely burned, the 0.018 moles of water formed was absorbed by anhydrous calcium chloride.
Then the carbon dioxide produced in the combustion of **X** was absorbed by potassium hydroxide. It was found that 3.584 g of potassium hydroxide reacted with this carbon dioxide according to the following balanced equation.

$$\mathbf{CO_2 + 2KOH \rightarrow K_2CO_3 + H_2O}$$

It was also found that 44.8 cm^3 of $\mathbf{SO_2}$, measured at s.t.p., and 2.4×10^{21} molecules of $\mathbf{NO_2}$ were obtained in the combustion of **X**.

In the sample of **X** that was burned, calculate the number of moles of
(*i*) hydrogen (**H**),
(*ii*) carbon (**C**),
(*iii*) sulfur (**S**),
(*iv*) nitrogen (**N**).

If there were also 0.008 moles of oxygen (**O**) in the sample that was burned, what is the empirical formula of **X**, listing the elements in alphabetical order? (25)

Question 9

7. (*a*) (*i*) Explain how an acid differs from a base according to the Brønsted-Lowry theory.

(*ii*) Explain how a strong acid differs from a weak acid according to the Brønsted-Lowry theory.

(*iii*) What is a conjugate acid-base pair?

(*iv*) Identify the conjugate acid-base pairs in the following reaction:

$$\mathbf{HCO_3^-}_{(aq)} + \mathbf{H_2O}_{(l)} \rightleftharpoons \mathbf{H_2CO_3}_{(aq)} + \mathbf{OH^-}_{(aq)}$$ (13)

(*b*) (*i*) Explain what is meant by pH.

(*ii*) Calculate the $\mathbf{H_3O^+}$ ion concentration, in moles per litre, of a solution of a strong acid with pH = 1.4.

(*iii*) Calculate the pH of a 0.015 M solution of a weak monobasic acid with $K_a = 3.2 \times 10^{-4}$ at 25 °C. (15)

(*c*) (*i*) Write an expression for the ionic product of water (K_w).

The ionic product of water (K_w) at 60 °C is 9.61×10^{-14} mol^2 l^{-2}.

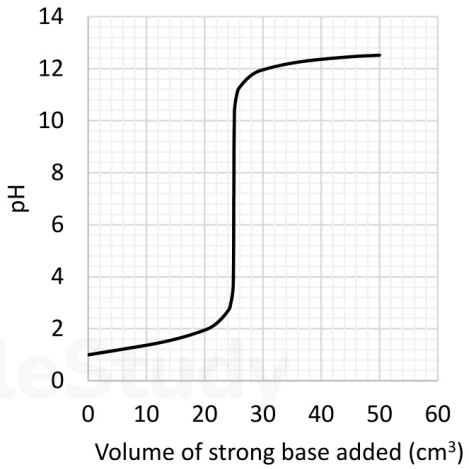
(*ii*) Calculate the pH of pure water at 60 °C. (12)

(*d*) A certain water-soluble acid-base indicator, represented by **HA**, is a weak acid which dissociates in water as described by the following balanced equation:

$$\underset{\text{yellow}}{\mathbf{HA}} + \mathbf{H_2O} \rightleftharpoons \mathbf{H_3O^+} + \underset{\text{blue}}{\mathbf{A^-}}$$

(*i*) State the colour you would expect to observe when a few drops of **HA** are added to a solution of a strong base. Justify your answer.

The pH curve on the right shows the change of pH as 50 cm^3 of a solution of a strong base were added to 25 cm^3 of a solution of a strong monobasic acid.
The indicator **HA** changes colour in the pH range of 4.2 to 5.4.



(*ii*) Would the indicator **HA** be a suitable choice of indicator for the titration? Justify your answer. (10)