Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE A LEVEL

A410U10-1

S23-A410U10-1

MONDAY, 12 JUNE 2023 – MORNING

CHEMISTRY – A level component 1

Physical and Inorganic Chemistry

2 hours 30 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 6.**	**15**	
Section B	**7.**	**19**	
	8.	**17**	
	9.	**13**	
	10.	**24**	
	11.	**18**	
	12.	**14**	
	Total	**120**	

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ADDITIONAL MATERIALS

- A calculator
- **Data Booklet** supplied by WJEC.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen.
Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 120.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q.7**(a) and **Q.11**(a).

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SECTION A

Answer **all** questions.

1. The electronegativity values of some elements are listed in the table.

Element	Si	F	Cl
Electronegativity value	1.8	4.0	3.5

(a) State what is meant by the term electronegativity. [1]

The ability of an atom to attract the bonding pair of electrons in a covalent bond.

(b) Label the bonds below with δ+ and δ– to show any dipoles that are present. [1]

δ+ δ–
Si — Cl

δ– δ+
F — Cl

2. Name the feature of the atomic emission spectrum of hydrogen that can be used to find the ionisation energy of the atom. [1]

The convergence limit of the Lyman series (where the lines converge).

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3. There are many isotopes of the artificial element americium.

(a) One isotope of americium has a half-life of 12 hours.

Calculate the percentage of a sample of this isotope that would remain after 2 days. [2]

2 days = 48 hours = 48 ÷ 12 = 4 half-lives

percentage remaining = 100 × $(½)^4$ = 100 ÷ 16 = 6.25 %

Percentage remaining = 6.25 %

(b) Another isotope of americium, ^{238}Am, can decay by either positron emission or by α-emission.

Identify the isotopes produced in both cases. [2]

Positron emission

Element symbol Pu Mass number 238

α-emission

Element symbol Np Mass number 234

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4. An iodine clock reaction was studied using different concentrations of reactants.

The time taken for the colour to change was measured.

Concentration of I^- / mol dm^{-3}	Concentration of H_2O_2 / mol dm^{-3}	Time for colour change / s	Rate
0.20	0.10	49.7	0.020
0.20	0.20	24.9	0.040
0.40	0.20	12.4	0.081

(a) (i) Complete the table with the rate values for these experiments. [1]

(ii) Give the unit of rate for these experiments. [1]

Unit s^{-1}

(b) Describe the relationship between the concentration of hydrogen peroxide and the rate of reaction. [1]

The rate is directly proportional to the concentration of H_2O_2 (first order with respect to H_2O_2): doubling $[H_2O_2]$ doubles the rate.

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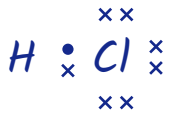
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5. Hydrogen chloride forms the strong acid hydrochloric acid when dissolved in water.

In one experiment the pH of the hydrochloric acid formed was 0.32.

(a) Draw a dot and cross diagram for hydrogen chloride. [1]



(b) State what is meant by the term strong acid. [1]

An acid (molecule) that dissociates fully (completely ionises) in water, releasing H^+ ions.

(c) Calculate the concentration of hydrochloric acid of pH 0.32. [1]

$[H^+] = 10^{-pH} = 10^{-0.32}$

$= 0.479 \text{ mol dm}^{-3}$

Concentration = 0.48 mol dm^{-3}

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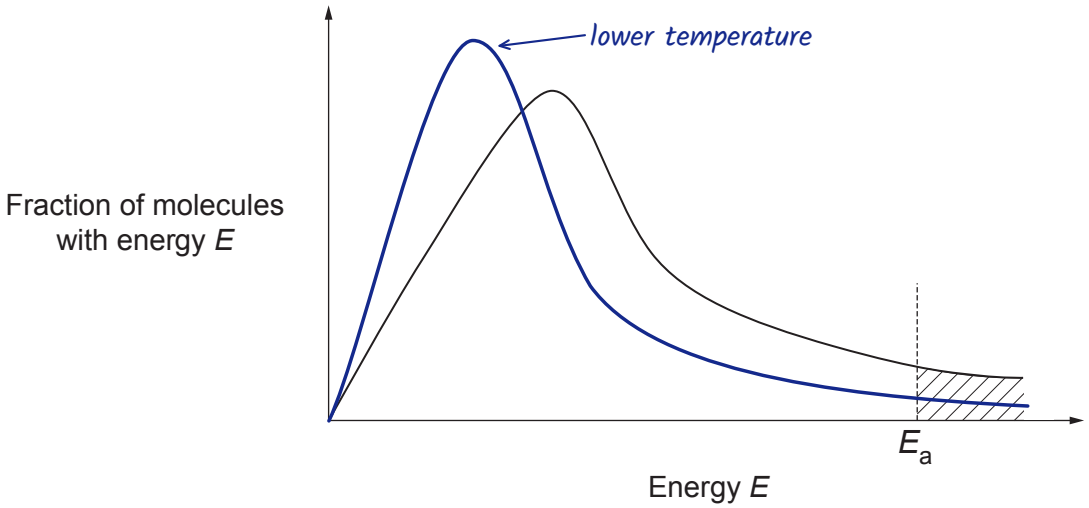
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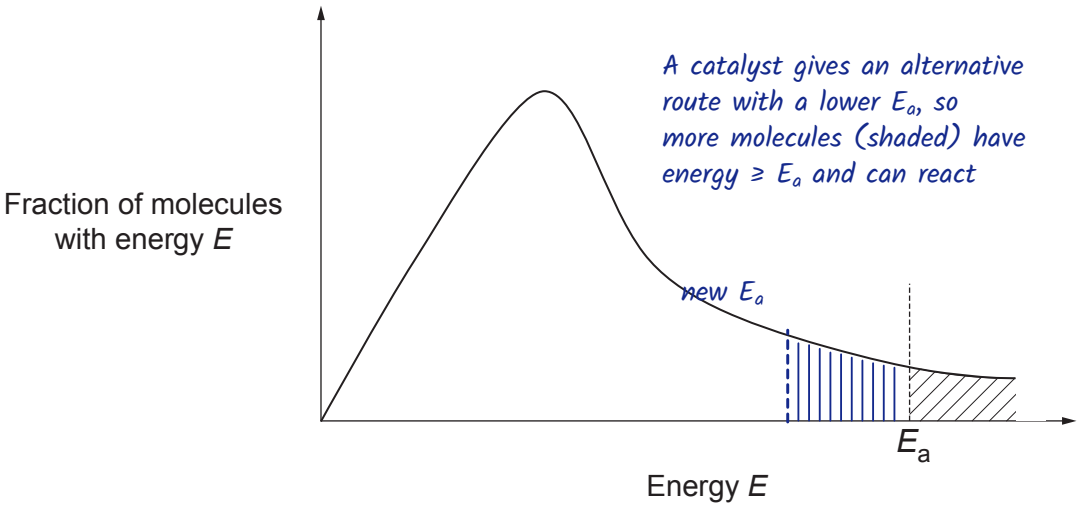
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6. The graphs below show the energy distribution of particles at 298 K.

(a) Sketch the distribution at a lower temperature on the same axes. [1]



(b) Label the graph to show how catalysts increase the rate of chemical reactions. [1]



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SECTION B

Answer **all** questions.

7. The elements at the top and bottom of Group 4 have very different physical and chemical properties.

(a) Describe the bonding and structures present in lead and **one** common elemental form of carbon.

You should explain how the bonding and structures affect the melting temperatures and electrical conductivity of these elements. [6 QER]

Lead has metallic bonding: a giant lattice of Pb^{2+} ions in a sea of delocalised electrons, held by the strong electrostatic attraction between the positive ions and the delocalised electrons.

To melt lead, these forces between the metal ions and the delocalised electrons must be overcome. Lead has a fairly low melting temperature for a metal, much lower than carbon. Lead conducts electricity because the delocalised electrons can move through the lattice and carry a current.

Carbon (graphite) is a giant covalent (macromolecular) structure. Each carbon atom is covalently bonded to 3 others, forming flat hexagonal layers, with weak van der Waals forces between the layers. The fourth electron of each atom is delocalised between the layers.

Graphite has a very high melting temperature because many strong covalent bonds must be broken. It conducts electricity because the delocalised electrons can move along the layers to form a current.

(In diamond each carbon is bonded tetrahedrally to 4 others, so there are no delocalised electrons and diamond is an insulator, but it also has a very high melting temperature.)

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(b) A student is provided with a mixture of lead(II) oxide, PbO, and lead(IV) oxide, PbO_2.

To find the percentage by mass of each oxide in the sample the student treats the mixture with iodide ions in acid solution.

- Lead(IV) oxide oxidises the iodide ions in acid solution. This produces a precipitate of lead(II) iodide and an aqueous solution of iodine.

$$PbO_2 + 4I^- + 4H^+ \longrightarrow PbI_2 + I_2 + 2H_2O$$

- Lead(II) oxide reacts with the iodide ions in acid solution. This produces a precipitate of lead(II) iodide.

$$PbO + 2I^- + 2H^+ \longrightarrow PbI_2 + H_2O$$

The solution and solid are separated by filtration. The solid is washed in cold water and the washings added to the solution. The solution is titrated using aqueous sodium thiosulfate of concentration 0.100 mol dm^{-3} to find the amount of iodine present. The solid sample is heated to constant mass.

The results are given below.

Mass of precipitate = 2.425 g

Volume of aqueous sodium thiosulfate required = 33.45 cm^3

(i) Give the colour of the lead(II) iodide precipitate. [1]

bright (canary) yellow

(ii) Calculate the number of moles of lead(II) iodide formed. [2]

$M_r(PbI_2) = 207.2 + (2 \times 126.9) = 461$

$n = mass \div M_r = 2.425 \div 461 = 5.26 \times 10^{-3}$ mol

Number of moles = 5.26×10^{-3} mol

(iii) The thiosulfate ions act as reducing agents.

$$2S_2O_3^{2-} \longrightarrow S_4O_6^{2-} + 2e^-$$

Write the equation for the reduction of iodine by thiosulfate ions. [1]

$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$

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(iv) Suggest a suitable indicator for this titration, giving the colour change expected at the endpoint. [2]

Starch (added near the end point, when the solution is pale yellow).

Colour change: blue-black to colourless.

(v) Calculate the number of moles of lead(IV) oxide present. [3]

moles $S_2O_3^{2-}$ = 0.100 × 33.45 ÷ 1000 = 3.345 × 10^{-3} mol

moles I_2 = 3.345 × 10^{-3} ÷ 2 = 1.673 × 10^{-3} mol

1 mol PbO_2 gives 1 mol I_2, so

moles PbO_2 = 1.673 × 10^{-3} mol

Number of moles = 1.673 × 10^{-3} mol

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(vi) Calculate the percentage by mass of lead(IV) oxide in the initial sample. [4]

$M_r(PbO)$ = 223 $M_r(PbO_2)$ = 239

mass PbO_2 = 1.673 × 10^{-3} × 239 = 0.400 g

moles PbO = 5.26 × 10^{-3} − 1.673 × 10^{-3} = 3.587 × 10^{-3} mol

mass PbO = 3.587 × 10^{-3} × 223 = 0.800 g

% PbO_2 = 0.400 ÷ (0.400 + 0.800) × 100 = 33.3 %

Percentage by mass = 33.3 %

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8. Transition metals form a range of ions that can combine with ligands to form complex ions.

(a) Write the electron arrangement for the Mn^{2+} ion. [1]

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$

(b) (i) Cobalt(II) ions form complexes including $[CoCl_4]^{2-}$ and $[Co(H_2O)_6]^{2+}$.

State the colours of these ions in aqueous solution. [2]

$[CoCl_4]^{2-}$ blue

$[Co(H_2O)_6]^{2+}$ pink

(ii) Explain why octahedral transition metal complexes such as $[Co(H_2O)_6]^{2+}$ are coloured. [3]

The ligands split the d-orbitals into three lower and two higher energy levels.

Electrons absorb specific frequencies of visible light to be excited from the lower to the higher energy levels ($\Delta E = hf$).

The colour seen is the light that is not absorbed (reflected or transmitted).

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(c) Transition metal compounds are used in heterogeneous catalysts for a range of industrial processes.

(i) State what is meant by the term heterogeneous catalyst. [1]

A catalyst that is in a different physical state (phase) to the reactants, e.g. a solid catalyst with gaseous reactants.

(ii) One industrial process that uses a heterogeneous catalyst is the carbonylation of methanol (Method 1).

$$CH_3OH + CO \rightleftharpoons CH_3COOH$$

This reaction is usually carried out in the gas phase.

An equimolar gas phase mixture of CH_3OH and CO is allowed to come to equilibrium and the resultant mixture contains 10.8% CH_3COOH at a total pressure of 3.21×10^6 Pa.

Calculate the value of K_p for this equilibrium giving its unit. [4]

% CH_3OH = % CO = (100 − 10.8) ÷ 2 = 89.2 ÷ 2 = 44.6 %

$p(CH_3COOH) = 0.108 \times 3.21 \times 10^6 = 3.47 \times 10^5$ Pa

$p(CH_3OH) = p(CO) = 0.446 \times 3.21 \times 10^6 = 1.43 \times 10^6$ Pa

$K_p = p(CH_3COOH) \div (p(CH_3OH) \times p(CO))$

$K_p = 3.47 \times 10^5 \div (1.43 \times 10^6 \times 1.43 \times 10^6)$

$K_p = 1.70 \times 10^{-7}$ Pa^{-1}

K_p = 1.70×10^{-7}

Unit Pa^{-1}

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(iii) An alternative method of producing CH_3COOH uses carbon dioxide and hydrogen as reactants in place of carbon monoxide (Method 2).

$$CH_3OH + CO_2 + H_2 \rightleftharpoons CH_3COOH + H_2O$$

This reaction occurs in solution using a homogeneous catalyst containing ruthenium and rhodium compounds and converts 14.0% of the methanol to ethanoic acid at a pressure of 4.20×10^6 Pa.

Suggest which of methods 1 and 2 is the better method. Give reasons for your answer. [3]

Method 1 is better. It runs at a lower pressure (3.21×10^6 Pa rather than 4.20×10^6 Pa), so less energy is needed to generate the pressure. It has 100% atom economy with no waste by-products, whereas method 2 forms water so has a lower atom economy. There is only one product, and CH_3COOH has a higher boiling point than CO and CH_3OH, so it is easier to condense and separate; the heterogeneous catalyst is easy to separate and reuse.

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(d) Most metals react with acids to produce a salt and hydrogen gas. Copper metal does not react in this way but it does react with nitric acid, HNO_3, in a different reaction.

Use the values of standard electrode potentials given in the table to explain these observations, writing an equation for the reaction you expect to occur between copper metal and nitric acid. [3]

	Standard electrode potential, E^{θ}/V
$2H^+ + 2e^- \rightleftharpoons H_2$	+0.00
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.33
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+0.81

Equation $Cu + 2NO_3^- + 4H^+ \rightarrow Cu^{2+} + 2NO_2 + 2H_2O$

EMF for Cu with H^+ = 0.00 − 0.33 = −0.33 V; this is negative so the reaction is not feasible: $E^{\ominus}$ for Cu^{2+}/Cu is more positive than for H^+/H_2, so Cu cannot reduce H^+ to H_2.

EMF for Cu with NO_3^- in acid = 0.81 − 0.33 = +0.48 V; this is positive so the reaction is feasible: Cu^{2+}/Cu is more negative than NO_3^-/NO_2, so Cu can reduce NO_3^- to NO_2.

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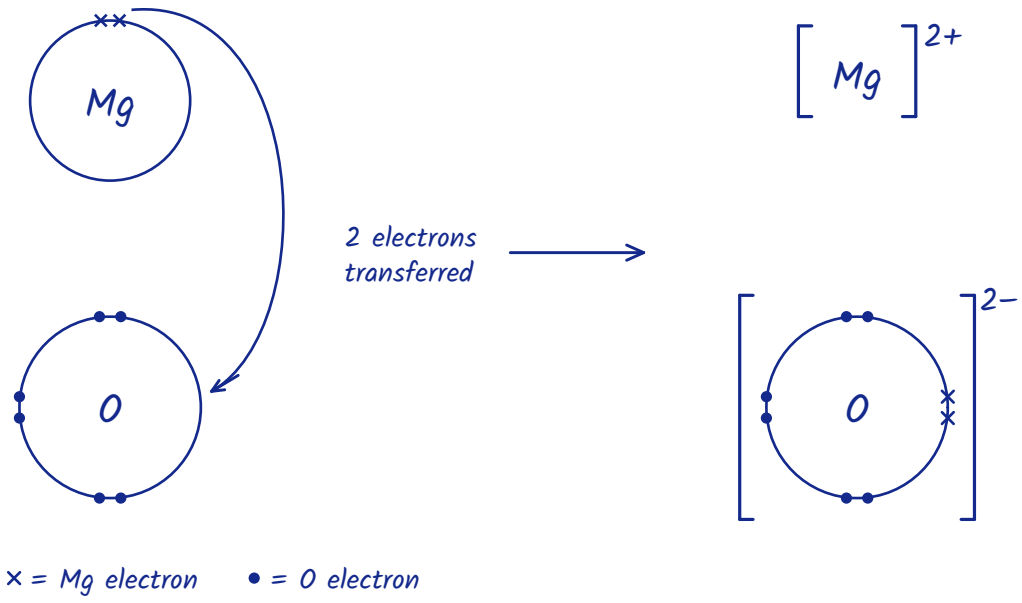
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9. Most Group 2 elements form oxides with similar properties.

(a) Draw a dot and cross diagram for the formation of magnesium oxide from atoms of its elements. [2]



(b) The enthalpy change of formation of magnesium oxide can be found experimentally by measuring the temperature rise in two reactions and calculating their respective enthalpy changes.

- Adding magnesium metal to an excess of dilute acid
- Adding magnesium oxide to an excess of dilute acid

Two students performed the experiment using the following method.

- Measure 50 cm^3 of hydrochloric acid of concentration 1.0 mol dm^{-3} using a burette and place in a polystyrene cup.
- Place a lid on the cup and fit a thermometer through this. The thermometer measures to the nearest 0.2°C.
- Measure the temperature every 30 seconds for 3 minutes.
- Measure precisely a known amount of magnesium metal.
- Add the solid at precisely 3 minutes, stirring well.
- Measure the temperature every 30 seconds for another 4 minutes.
- Repeat these steps using magnesium oxide.
- Plot the results and calculate the enthalpy changes.

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(i) Tom decides to use the same mass of magnesium metal and magnesium oxide in his two experiments. He measures precisely 0.200 g of each and obtains the following results.

Results with magnesium metal

Time / s	0	30	60	90	120	150	180	210	240	270	300	330	360	390	420
Temperature / °C	19.2	19.4	19.4	19.4	19.4	19.4	xx	37.2	38.8	38.8	38.8	38.6	38.6	38.4	38.4

Results with magnesium oxide

Time / s	0	30	60	90	120	150	180	210	240	270	300	330	360	390	420
Temperature / °C	19.2	19.4	19.4	19.4	19.4	19.4	xx	22.0	22.4	22.8	22.8	22.6	22.6	22.6	22.4

Tom's teacher told him that his choice of mass of magnesium oxide has not given him suitable results and that he should repeat his experiment with a different mass.

I. Suggest why Tom's mass of magnesium oxide did not give suitable results. [1]

The temperature rise is too small (only 3.4 °C), so the percentage error in the temperature change is too large.

II. Tom decides to repeat both experiments using a mass of 1.00 g of each solid.

Suggest **two** reasons why 1.00 g would not be a suitable mass of magnesium metal to use. [2]

The temperature would rise by about 5 × 19.4 ≈ 97 °C, so it would reach 100 °C and the solution would boil.

1.00 g Mg = 0.041 mol, but 0.050 mol HCl reacts with only 0.025 mol Mg, so the acid would no longer be in excess.

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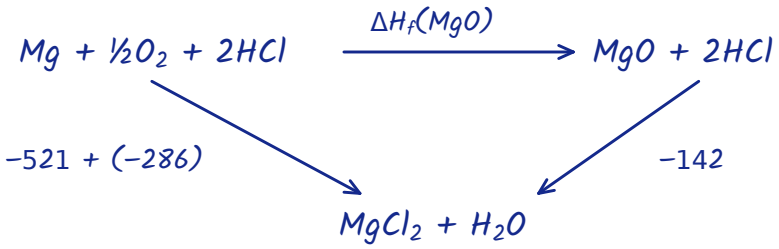
(ii) Cerys carried out the same experiments and obtained the following enthalpy change values. All substances were in their standard states.

$Mg + 2HCl \longrightarrow MgCl_2 + H_2$ $\quad \Delta H = -521\,kJ\,mol^{-1}$

$MgO + 2HCl \longrightarrow MgCl_2 + H_2O$ $\quad \Delta H = -142\,kJ\,mol^{-1}$

The enthalpy change of formation of H_2O is $-286\,kJ\,mol^{-1}$.

Use this data to calculate the enthalpy change of formation of magnesium oxide. [3]



$\Delta H_f(MgO) = \Delta H(Mg + acid) + \Delta H_f(H_2O) - \Delta H(MgO + acid)$

$\Delta H_f(MgO) = -521 + (-286) - (-142)$

$\Delta H_f(MgO) = -665\ kJ\ mol^{-1}$

$\Delta H =$ ..−665.. $kJ\,mol^{-1}$

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(c) Barium oxide can be formed by heating barium carbonate.

$$BaCO_3(s) \longrightarrow BaO(s) + CO_2(g) \qquad \Delta H = 243\,kJ\,mol^{-1}$$

	$BaCO_3(s)$	$BaO(s)$	$CO_2(g)$
Standard entropy / $J\,K^{-1}\,mol^{-1}$	112	70	214

(i) Give a reason why the standard entropy values of $BaCO_3$ and BaO are lower than that of CO_2. [1]

$BaCO_3$ and BaO are solids, which are more ordered (less disordered) than gases such as CO_2.

(ii) Calculate the minimum temperature required for the thermal decomposition of barium carbonate. [4]

$\Delta S = (70 + 214) - 112 = +172\ J\ K^{-1}\ mol^{-1} = 0.172\ kJ\ K^{-1}\ mol^{-1}$

minimum temperature when $\Delta G = \Delta H - T\Delta S = 0$

$T = \Delta H \div \Delta S$

$T = 243 \div 0.172 = 1413\ K$

$T =$ 1413 K

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10. Chlorine forms a range of oxides and oxyanions. Many of these are reactive species that can oxidise or chlorinate a range of elements and compounds.

(a) Dichlorine heptoxide, Cl_2O_7, is a colourless liquid that can be formed by reaction of ozone with chlorine in the presence of ultraviolet light.

$$3Cl_2(g) + 7O_3(g) \longrightarrow 3Cl_2O_7(g) \qquad \Delta H^{\theta} = -199\,kJ\,mol^{-1}$$

Substance	Standard enthalpy change of formation, $\Delta_f H^{\theta}$ / kJ mol^{-1}
$Cl_2(g)$	0
$O_3(g)$	142

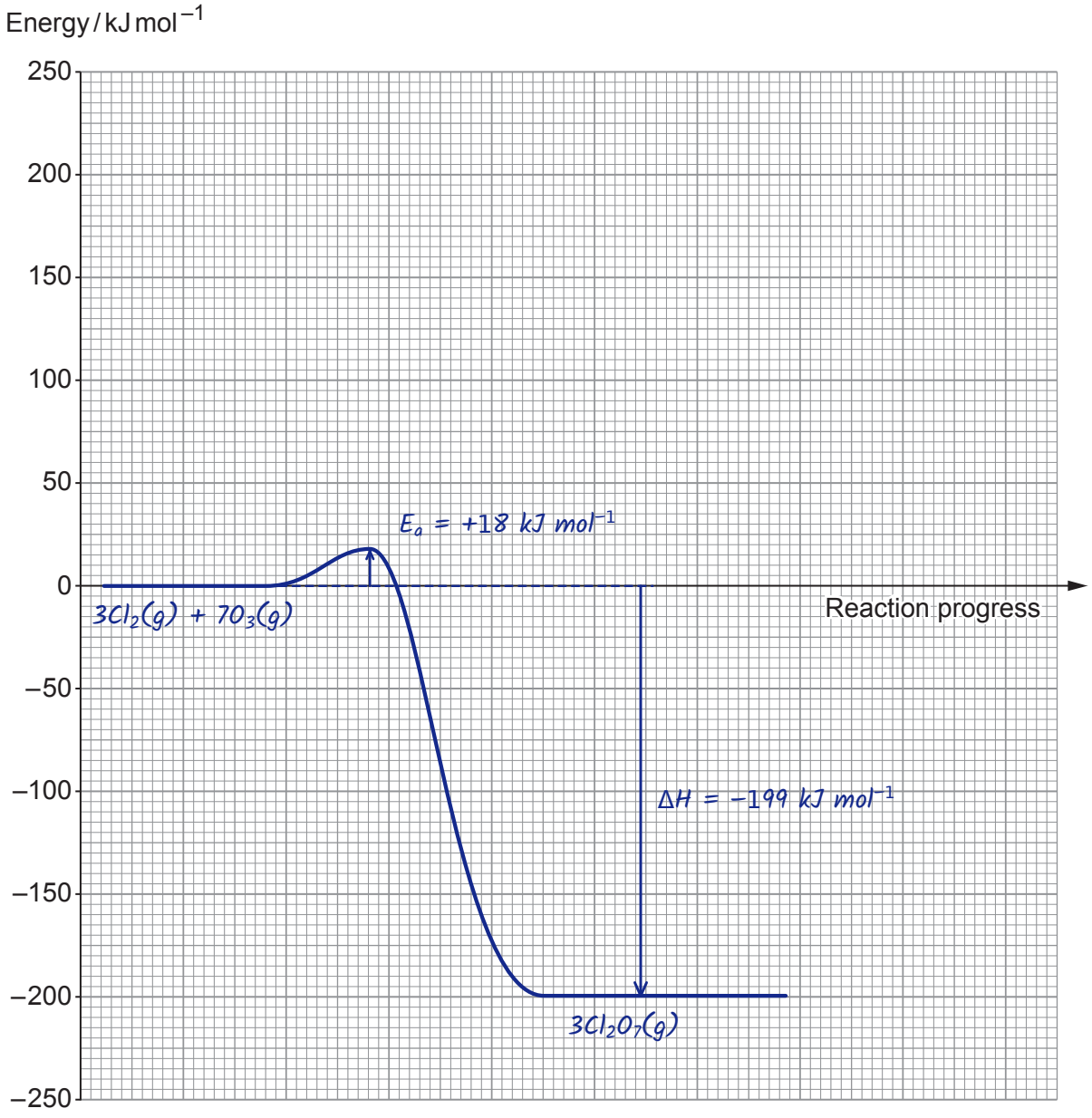
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(i) The activation energy for this reaction is 18 kJ mol^{-1}.

Draw the energy profile for this reaction on the axes provided. [3]



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(ii) The reaction is carried out at a temperature of 223 K and the rate constant is found to have a value of 2.24×10^3. The unit of the rate constant is not stated.

Calculate the temperature required to double the rate of reaction. [4]

$E_a = 18\ kJ\ mol^{-1} = 18000\ J\ mol^{-1}$

$k = Ae^{-Ea/RT}$: $A = 2.24 \times 10^3 \div e^{-18000/(8.31 \times 223)}$

$A = 2.24 \times 10^3 \times e^{9.713} = 3.704 \times 10^7$

double the rate, so $2k = 4.48 \times 10^3$

$T = -E_a \div (R \ln(2k \div A))$

$T = -18000 \div (8.31 \times \ln(4.48 \times 10^3 \div 3.704 \times 10^7))$

$T = -18000 \div (8.31 \times -9.020) = 240\ K$

$T =$ 240 K

(iii) The rate equation for this reaction is first order with respect to each reactant and the rate is measured in units of $mol\,dm^{-3}\,s^{-1}$.

I. Write the rate equation. [1]

$rate = k[Cl_2][O_3]$

II. Give the unit of the rate constant. [1]

$mol^{-1}\ dm^3\ s^{-1}$

(iv) Explain why the standard enthalpy of formation for chlorine gas is zero but that of ozone is not. [2]

$Cl_2(g)$ is an element in its standard state, so its enthalpy of formation is zero.

Ozone, O_3, is not the standard state of oxygen ($O_2(g)$ is), so its enthalpy of formation is not zero.

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(v) Dichlorine heptoxide decomposes readily to form $Cl_2(g)$ and $O_2(g)$.

$$2Cl_2O_7(g) \longrightarrow 2Cl_2(g) + 7O_2(g)$$

Calculate the volume of gas produced when 2.70 g of Cl_2O_7 decomposes at a temperature of –12°C and 1 atm pressure. [4]

$M_r(Cl_2O_7) = (2 \times 35.5) + (7 \times 16.0) = 183$

moles $Cl_2O_7 = 2.70 \div 183 = 1.475 \times 10^{-2}$ mol

2 mol $Cl_2O_7 \rightarrow 9$ mol gas, so each forms 4½ mol of gas

moles gas $= 4.5 \times 1.475 \times 10^{-2} = 6.64 \times 10^{-2}$ mol

$T = -12 + 273 = 261$ K; $p = 1.01 \times 10^5$ Pa

$V = nRT \div p = (6.64 \times 10^{-2} \times 8.31 \times 261) \div 1.01 \times 10^5$

$V = 1.43 \times 10^{-3}$ m^3 = 1.43 dm^3

Volume = ... 1.43 ..... dm^3

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(b) Chlorine dioxide, ClO_2, is an unstable oxide of chlorine. It is often stored in aqueous solution and in some countries solutions can only be transported if the concentration is lower than 0.30 g in 100 cm^3 of water.

Calculate the concentration of this solution in mol dm^{-3}. [2]

0.30 g in 100 cm^3 = 3.0 g dm^{-3}

$M_r(ClO_2)$ = 35.5 + (2 × 16.0) = 67.5

concentration = 3.0 ÷ 67.5 = 4.4 × 10^{-2} mol dm^{-3}

Concentration = *4.4 × 10^{-2}* mol dm^{-3}

(c) Chlorine perchlorate, $ClOClO_3$, is an oxide with the two chlorine atoms in different oxidation states.

(i) If one chlorine atom has an oxidation state of +1, find the oxidation state of the other. [1]

+7

(ii) Predict the appearance of the molecular ion peaks seen in the mass spectrum of chlorine perchlorate. Give reasons for your answer.

You should refer to both the positions and heights of the peaks. [4]

Chlorine has two isotopes, ^{35}Cl and ^{37}Cl, present in a 3 : 1 ratio, so there are three molecular ion peaks.

Peaks at m/z 134 ($^{35}ClO^{35}ClO_3$), 136 ($^{35}ClO^{37}ClO_3$ and $^{37}ClO^{35}ClO_3$) and 138 ($^{37}ClO^{37}ClO_3$).

Heights in the ratio 9 : 6 : 1. The 134 peak is 9 times the 138 peak (3^2 : 1^2); the 136 peak is 6 times the 138 peak, as (3 × 1) + (1 × 3) = 6.

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(d) The chlorite ion, $O=Cl-O^-$, has a non-linear shape.

Explain why this ion is not linear. [2]

The Cl atom has two lone pairs as well as two bonded pairs (bonding regions) of electrons around it.

The electron pairs repel to be as far apart as possible, based on a tetrahedral arrangement, and lone pairs repel more than bonded pairs, so the ion is V-shaped (bent, like water).

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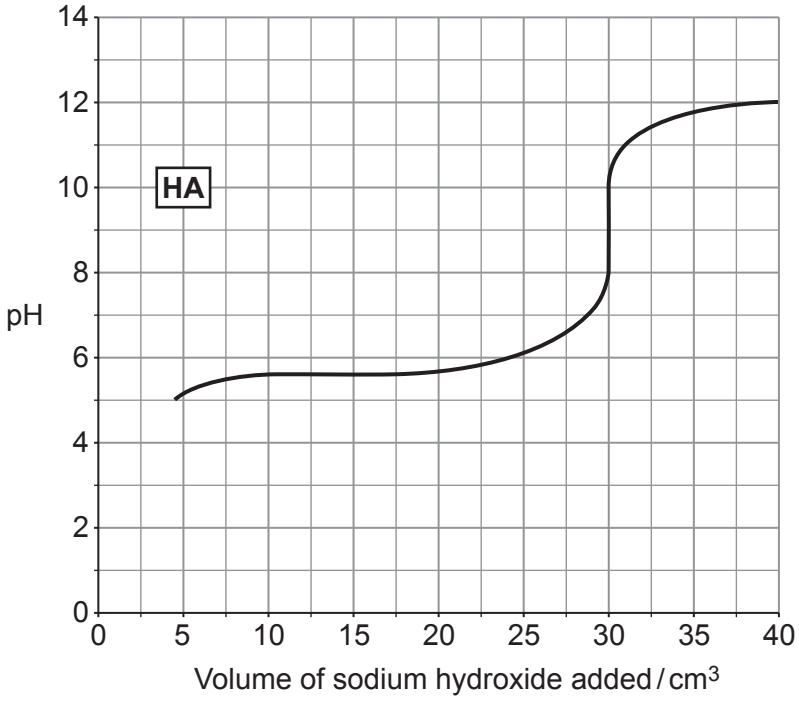
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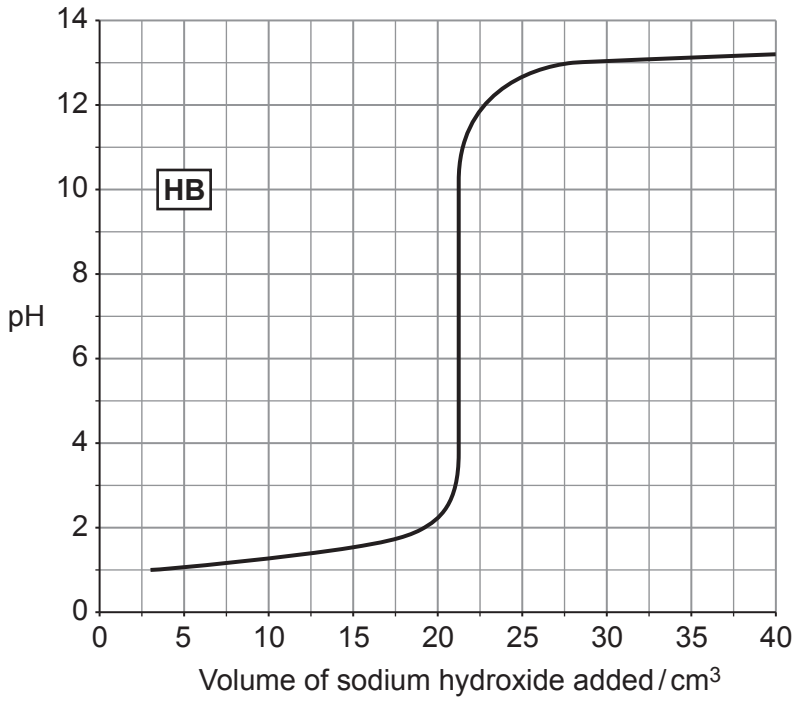
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11. A student carried out two acid-base titrations using two acids, HA and HB.

A 25.0 cm^3 sample of each acid was titrated against a sodium hydroxide solution of concentration 0.150 mol dm^{-3} giving the titration curves shown. The initial pH values are missing from both graphs.

One acid is a strong acid and one is a weak acid.





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(a) Describe and explain the differences between the two curves.

- You should identify which acid is strong and which is weak, explaining fully how you have reached your conclusion.
- You should identify which acid is more concentrated and which is more dilute, explaining how you have reached your conclusion.

[6 QER]

HA is the weak acid and HB is the strong acid. Early in the titration (after adding 5 to 15 cm^3 of NaOH) the pH of HA is higher (about 5 to 6) than that of HB (about 1 to 2), so HA has fewer H^+ ions as it is only partially dissociated.

The vertical region of the HA curve is shorter (pH about 7.5 to 10.5) than that of HB (pH about 3 to 11), so the equivalence point for HA is at a higher pH (about 9), as expected for a weak acid with a strong base. HA also shows a flattening at around 15 cm^3 of NaOH due to the buffer effect of HA and A^-, which HB does not.

HA is more concentrated than HB, as more NaOH is needed to neutralise HA: the equivalence point is at 30.0 cm^3 for HA but about 21.25 cm^3 for HB.

Both acids are monobasic and the same volume (25.0 cm^3) was used, so [HA] = 0.150 × 30.0 ÷ 25.0 = 0.180 mol dm^{-3} and [HB] = 0.150 × 21.25 ÷ 25.0 = 0.128 mol dm^{-3}, so HB is more dilute.

(b) Calculate K_a for the weak acid. [2]

at the half-neutralisation point of HA (15 cm^3), [HA] = $[A^-]$

so pH = pK_a = 5.6

$K_a = 10^{-5.6} = 2.51 \times 10^{-6}$ mol dm^{-3}

K_a = 2.51 × 10^{-6} mol dm^{-3}

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(c) Both these titrations can be performed using appropriate acid-base indicators, but similar experiments using a weak acid and a weak base cannot use acid-base indicators successfully. Explain this difference. [2]

Indicators must change colour in a vertical region of the curve. The titrations of HA and HB both have a vertical region, but a weak acid and weak base titration does not.

(d) The students made 250 cm^3 of aqueous sodium hydroxide of concentration 0.150 mol dm^{-3} for these experiments.

(i) Calculate the mass of NaOH required to make this solution. [2]

mol NaOH = 0.250 × 0.150 = 0.0375 mol

M_r(NaOH) = 23.0 + 16.0 + 1.0 = 40.0

mass = 0.0375 × 40.0 = 1.50 g

Mass = 1.50 g

(ii) Outline how this solution could be made. [3]

Weigh 1.50 g of NaOH, place it in a beaker and add a small amount of deionised water, stirring with a glass rod to dissolve.

Transfer the solution to a 250 cm^3 volumetric flask using a funnel, and rinse the beaker, glass rod and funnel several times with deionised water, with all washings going into the flask.

Add deionised water up to the line (bottom of meniscus on the mark), put the stopper on and invert several times to mix thoroughly.

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(iii) Calculate the pH of this aqueous sodium hydroxide at 298 K. [3]

$[OH^-] = 0.150 \text{ mol dm}^{-3}$

$[H^+] = K_w \div [OH^-] = 1.00 \times 10^{-14} \div 0.150$

$[H^+] = 6.67 \times 10^{-14} \text{ mol dm}^{-3}$

$pH = -\log[H^+] = -\log(6.67 \times 10^{-14}) = 13.2$

pH = ... 13.2 .....

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12. (a) Five ionisation energies are represented by the letters **A**–**E** as shown below.

A 1st ionisation energy of helium

B final ionisation energy of nitrogen

C final ionisation energy of oxygen

D 1st ionisation energy of sodium

E 2nd ionisation energy of magnesium

The values of these five ionisation energies are given in the table.

Value of ionisation energy / kJ mol^{-1}	Letter representing the ionisation energy
84 078	C
64 360	B
2372	A
1450	E
496	D

Complete the table using letters **A**–**E** to show which ionisation energy corresponds to each value.

Give reasons for your choices. [5]

The first IE of helium and the final IEs of nitrogen and oxygen (A, B and C) are the largest values, because the electron is removed from the first shell with no shielding.

C > B > A because oxygen has the largest nuclear charge (8+) and helium the smallest (2+).

D and E remove an electron from the same electronic structure ($3s^1$: Na and Mg^+), but the greater nuclear charge of magnesium means E is higher (1450 > 496).

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(b) Three boiling temperatures are listed below.

–33°C –111°C –132°C

These are the boiling temperatures of NH_3, PH_3 and AsH_3. Identify which value corresponds to each compound.

Give reasons for your choices. [3]

Boiling temperature of NH_3 ..–33.. °C

Boiling temperature of PH_3 ..–132.. °C

Boiling temperature of AsH_3 ..–111.. °C

NH_3 is the only compound with hydrogen bonding between molecules; this is the strongest intermolecular force, so NH_3 has the highest boiling temperature. PH_3 and AsH_3 have only van der Waals' forces between molecules; AsH_3 has more electrons, so stronger van der Waals' interactions and the higher boiling temperature.

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(c) A student is provided with four solutions labelled **W**, **X**, **Y** and **Z** and is told that these contain common cations and anions that they have studied.

He observes that one solution is pale blue and the others are colourless. Flame tests on the solutions give apple-green and golden yellow flames with two solutions and unfamiliar colours with the others.

The student mixes pairs of solutions together and obtains the following results. He did not complete all the experiments.

Solution 1	Solution 2	Observation(s)
W	**X**	white precipitate that dissolves when excess solution **W** is added
W	**Y**	mixture of pale blue precipitate and white precipitate in a colourless solution
W	**Z**	no visible change
X	**Y**	white precipitate in a pale blue solution
X	**Z**	
Y	**Z**	white precipitate in a brown solution

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Identify the **four** compounds and give reasons for your decisions. [6]

Compound **W** barium hydroxide, $Ba(OH)_2$

Compound **X** lead(II) nitrate, $Pb(NO_3)_2$

Compound **Y** copper(II) sulfate, $CuSO_4$

Compound **Z** sodium iodide, NaI

Flames: golden yellow is Na^+, apple-green is Ba^{2+}; the pale blue solution contains $Cu^{2+}(aq)$.

Y + Z: white precipitate of CuI in a brown solution of $I_2(aq)$, so Y contains Cu^{2+} and Z contains I^-.

W + X: white precipitate dissolves in excess W, so it is an amphoteric hydroxide: X contains Pb^{2+} and W contains OH^-.

W + Y: pale blue $Cu(OH)_2$ and white $BaSO_4$ precipitates.

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END OF PAPER

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Question number	Additional page, if required. Write the question number(s) in the left-hand margin.

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GCE A LEVEL

A410U10-1A

S23-A410U10-1A

MONDAY, 12 JUNE 2023 – MORNING

CHEMISTRY – A level component 1
Data Booklet

Avogadro constant	N_A	$= 6.02 \times 10^{23}\ \text{mol}^{-1}$
molar gas constant	R	$= 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
molar gas volume at 273 K and 1 atm	V_m	$= 22.4\ \text{dm}^3\ \text{mol}^{-1}$
molar gas volume at 298 K and 1 atm	V_m	$= 24.5\ \text{dm}^3\ \text{mol}^{-1}$
Planck constant	h	$= 6.63 \times 10^{-34}\ \text{J s}$
speed of light	c	$= 3.00 \times 10^{8}\ \text{m s}^{-1}$
density of water	d	$= 1.00\ \text{g cm}^{-3}$
specific heat capacity of water	c	$= 4.18\ \text{J g}^{-1}\ \text{K}^{-1}$
ionic product of water at 298 K	K_w	$= 1.00 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$
fundamental electronic charge	e	$= 1.60 \times 10^{-19}\ \text{C}$

temperature (K) = temperature (°C) + 273

$1\ \text{dm}^3 = 1000\ \text{cm}^3$
$1\ \text{m}^3 = 1000\ \text{dm}^3$
1 tonne = 1000 kg
$1\ \text{atm} = 1.01 \times 10^5\ \text{Pa}$

Multiple	Prefix	Symbol
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m

Multiple	Prefix	Symbol
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G

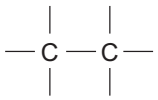
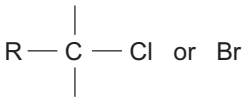
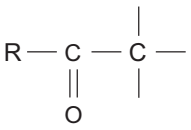
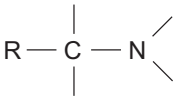
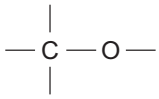
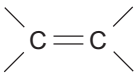
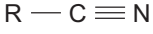
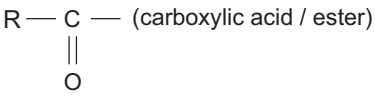
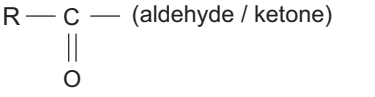
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Infrared absorption values

Bond	Wavenumber / cm^{-1}
C — Br	500 to 600
C — Cl	650 to 800
C — O	1000 to 1300
C = C	1620 to 1670
C = O	1650 to 1750
C ≡ N	2100 to 2250
C — H	2800 to 3100
O — H (carboxylic acid)	2500 to 3200 (very broad)
O — H (alcohol / phenol)	3200 to 3550 (broad)
N — H	3300 to 3500

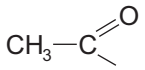
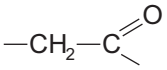
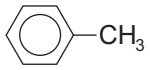
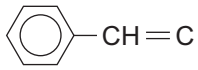
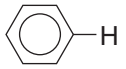
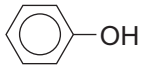
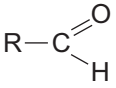
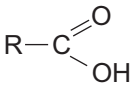
^{13}C NMR chemical shifts relative to TMS = 0

Type of carbon	Chemical shift, δ (ppm)
	5 to 40
	10 to 70
	20 to 50
	25 to 60
	50 to 90
	90 to 150
	110 to 125
	110 to 160
	160 to 185
	190 to 220

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^{1}H NMR chemical shifts relative to TMS = 0

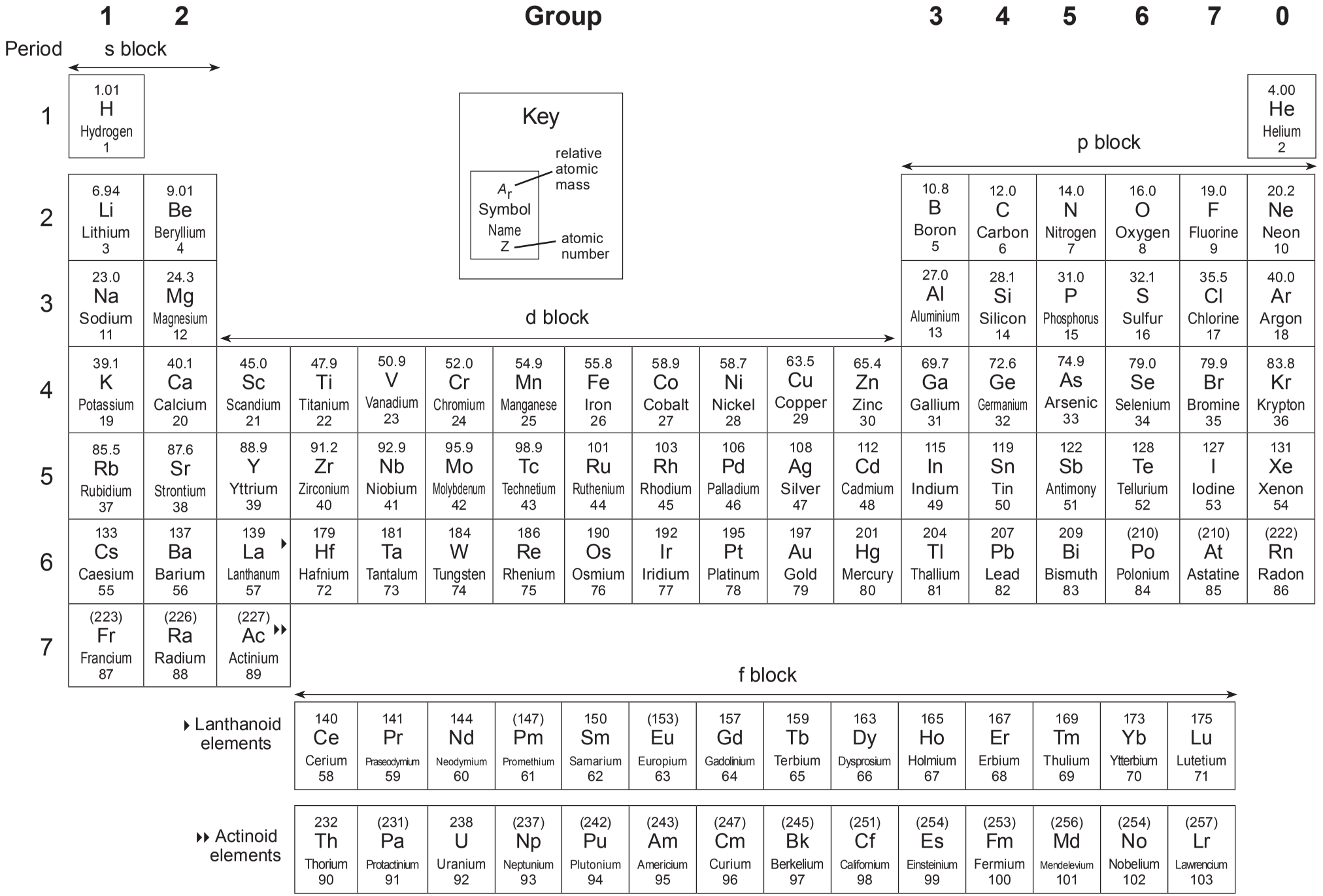
Type of proton	Chemical shift, δ (ppm)
$-CH_3$	0.1 to 2.0
$R-CH_3$	0.9
$R-CH_2-R$	1.3
$CH_3-C\equiv N$	2.0
	2.0 to 2.5
	2.0 to 3.0
	2.2 to 2.3
HC—Cl or HC—Br	3.1 to 4.3
HC—O	3.3 to 4.3
R—OH	4.5 *
—C=CH	4.5 to 6.3
—C=CH—CO	5.8 to 6.5
	6.5 to 7.5
	6.5 to 8.0
	7.0 *
	9.8 *
	11.0 *

*variable figure dependent on concentration and solvent

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THE PERIODIC TABLE



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(A410U10-1A)

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