Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME	

CENTRE NUMBER						CANDIDATE NUMBER					

* 4 7 1 3 5 3 6 2 2 7 *

CHEMISTRY **9701/43**

Paper 4 A Level Structured Questions **October/November 2024**

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS
- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION
- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **24** pages. Any blank pages are indicated.

DC (WW/CB) 336277/3

[Turn over

1 **(a)** Disodium phosphate, $(Na^+)_2(HPO_4^{2-})$, reacts with an acid to form monosodium phosphate, $Na^+(H_2PO_4^-)$.

(i) Identify the ions that are a conjugate acid–base pair in this reaction, using the formulae of the species involved.

conjugate acid	conjugate base
....	....

[1]

(ii) Define buffer solution.

....

.... [2]

(iii) Write **two** equations to show how a mixture of $(Na^+)_2(HPO_4^{2-})$ and $Na^+(H_2PO_4^-)$ can act as a buffer solution.

equation 1 ....

equation 2 ....
[2]

(iv) Identify **one** inorganic ion that acts as a buffer in blood.

.... [1]

(b) Compound **E** is the hydroxide of a Group 2 element. Compound **E** is a strong alkali.

2.63 g of **E** is dissolved in water to make 250 cm^3 of solution **F**. Solution **F** has a pH of 13.09 at 298 K.

(i) Show that the concentration of hydroxide ions in solution **F** is 0.123 $mol\,dm^{-3}$.

[2]

(ii) Explain why the concentration of compound **E** in solution **F** is 0.0615 $mol\,dm^{-3}$.

....

.... [1]

(iii) Use the concentration given in **(ii)** to identify compound **E**.

compound **E** .... [1]

(c) Compound **E** is much more soluble than magnesium hydroxide.

A saturated solution of magnesium hydroxide in water has a concentration of 1.40×10^{-4} mol dm^{-3} at 298 K.

Calculate the solubility product, K_{sp}, of magnesium hydroxide. Include units.

K_{sp} = ... units .... [3]

(d) Explain why compound **E** is much more soluble than magnesium hydroxide.

....

....

....

....

....

....

....

.... [3]

[Total: 16]

2 **(a)** Predict and explain the variation in enthalpy change of hydration for the ions F^-, Cl^-, Br^- and I^-.

....

....

.... [2]

(b) Fig. 2.1 shows an incomplete energy cycle involving calcium fluoride, CaF_2.

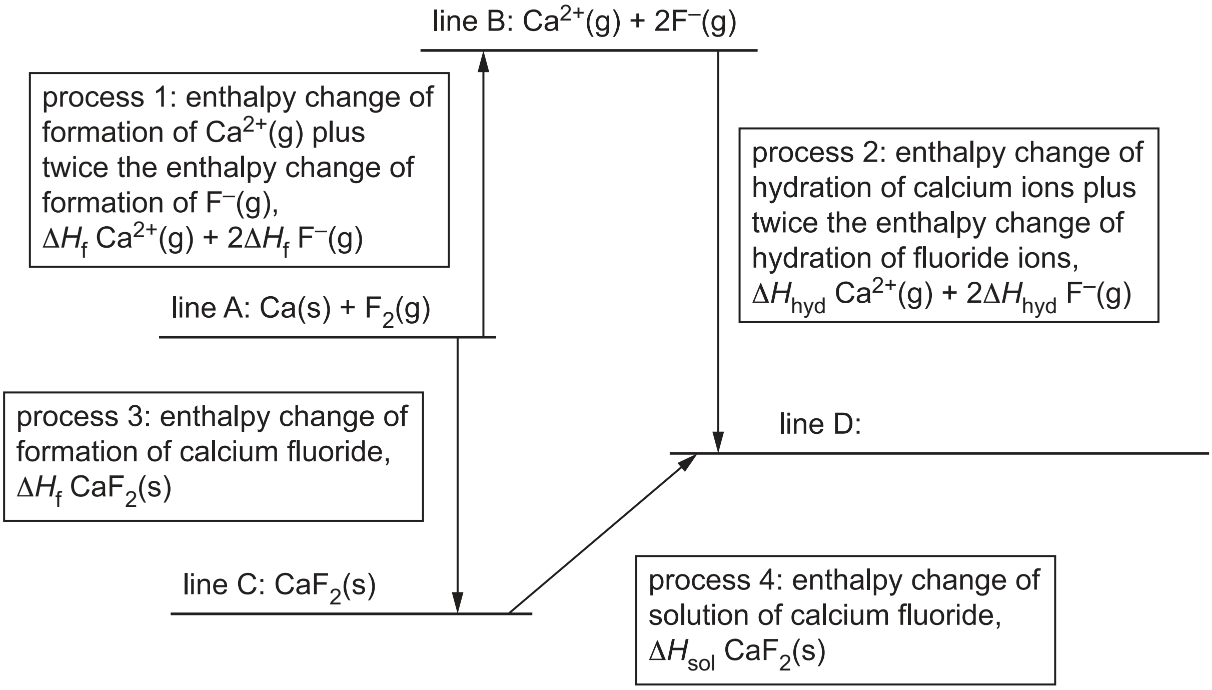


Fig. 2.1

(i) Complete line D. Include state symbols. [1]

(ii) The value of the enthalpy change for process 1 can be calculated using the values of **five** other enthalpy changes which are **not** referred to in Fig. 2.1.

process 1: $Ca(s) + F_2(g) \rightarrow Ca^{2+}(g) + 2F^-(g)$

Identify these **five** other enthalpy changes, using either names or symbols.

....

....

....

....

.... [2]

(iii) Define lattice energy, ΔH_{latt}.

....

....

.... [2]

(iv) Complete the expression to give the mathematical relationship between ΔH_{latt} of calcium fluoride and the enthalpy changes for processes 1 and 3.

ΔH_{latt} =

[1]

(c) Use data from Table 2.1 to calculate a value for the hydration energy, ΔH_{hyd}, of fluoride ions, $F^-(g)$.

Table 2.1

	value / kJ mol^{-1}
enthalpy change of solution of calcium fluoride, $CaF_2(s)$	+13
overall enthalpy change of process 1 in Fig. 2.1	+1395
enthalpy change of formation of calcium fluoride	–1214
enthalpy change of hydration of $Ca^{2+}(g)$	–1650

ΔH_{hyd} $F^-(g)$ = ... kJ mol^{-1} [2]

(d) Define entropy.

....

.... [1]

(e) At 298 K, the Gibbs free energy change, ΔG, for the solution of compound **T** is +6.00 kJ mol^{-1}.

The enthalpy change of solution, ΔH_{sol}, of compound **T** is +30.0 kJ mol^{-1} at 298 K.

Calculate the value of the entropy change, ΔS, for the solution of compound **T** at 298 K.

ΔS = ... J K^{-1} mol^{-1} [2]

(f) Predict whether compound **T** becomes more or less soluble as the water is heated from 298 K to 360 K. Explain your answer.

....

.... [1]

[Total: 14]

3 **(a)** A and B react together to give product AB.

$$A + B \rightarrow AB$$

When the concentrations of A and B are both 0.0100 mol dm^{-3}, the rate of formation of AB is 7.62×10^{-4} mol dm^{-3} s^{-1}. When the concentrations of A and B are both 0.0200 mol dm^{-3}, the rate of formation of AB is 3.05×10^{-3} mol dm^{-3} s^{-1}.

(i) Complete the **three** possible rate equations that are consistent with these data.

rate = ...

rate = ...

rate = ...

[2]

(ii) Choose **one** of the rate equations you have written in **(i)**, and calculate the value of the rate constant, *k*. Include the units of *k*.

k = ... units .... [2]

(iii) Explain why it is **not** possible to calculate a value for the half-life, $t_{\frac{1}{2}}$, of this reaction using the value of the rate constant *k* calculated in **(ii)** and the equation $k = 0.693 / t_{\frac{1}{2}}$.

....

....

.... [1]

(b) Catalysts may be homogeneous or heterogeneous.

(i) Identify **two** metals that act as heterogeneous catalysts in the removal of NO_2 from the exhaust gases of car engines.

.... and .... [1]

(ii) Iron acts as a heterogeneous catalyst in the Haber process.

Describe the mode of action of this iron catalyst.

....

....

.... [2]

(iii) Fe^{2+} ions act as a homogeneous catalyst in the reaction between $I^-(aq)$ and $S_2O_8^{2-}(aq)$.

Write equations for the **two** reactions that occur when $Fe^{2+}(aq)$ is added to a mixture of $I^-(aq)$ and $S_2O_8^{2-}(aq)$.

equation 1 $S_2O_8^{2-}$ + ...

equation 2 ....

[2]

(iv) Explain the difference between a homogeneous catalyst and a heterogeneous catalyst.

....

....

.... [1]

(c) Fe^{2+} ions can be oxidised to Fe^{3+} ions under alkaline conditions by suitable oxidising agents.

(i) Iron is a transition element. Explain why iron forms stable compounds in both the +2 and the +3 oxidation states.

.... [1]

(ii) The half-equation for the reduction of Fe^{3+} under alkaline conditions, and its $E^{\ominus}$ value, are shown.

$$Fe(OH)_3 + e^- \rightleftharpoons Fe(OH)_2 + OH^- \qquad E^{\ominus} = -0.56\,V$$

Four more half-equations for reactions under alkaline conditions, and their $E^{\ominus}$ values, are shown.

$$Al(OH)_4^- + 3e^- \rightleftharpoons Al + 4OH^- \qquad E^{\ominus} = -2.35\,V$$

$$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^- \qquad E^{\ominus} = +0.89\,V$$

$$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^- \qquad E^{\ominus} = +0.40\,V$$

$$Zn(OH)_4^{2-} + 2e^- \rightleftharpoons Zn + 4OH^- \qquad E^{\ominus} = -1.22\,V$$

Select **two** oxidising agents that can oxidise Fe^{2+} ions to Fe^{3+} ions under alkaline conditions.

Write an equation, and give the $E^{\ominus}_{cell}$ value, for **each** of the **two** reactions that occur.

oxidising agent 1: ....

equation: ....

$E^{\ominus}_{cell}$ = ... V

oxidising agent 2: ....

equation: ....

$E^{\ominus}_{cell}$ = ... V

[4]

[Total: 16]

4 Transition metal atoms and transition metal ions form complexes by combining with ligands.

(a) Explain why transition elements form complex ions.

....

.... [1]

(b) Co^{2+} ions form complex ion **G**.

Each **G** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated.

Each **G** ion contains one O_2 molecule, which donates one pair of electrons to **each** Co^{2+} ion, and one NH_2^- ion, which donates one pair of electrons to **each** Co^{2+} ion.

The remaining ligands are NH_3 molecules.

(i) Deduce the formula of complex ion **G**. Include its overall charge.

formula of **G** .... [2]

(ii) The d-orbitals of the Co^{2+} ions present in complex ion **G** are split. State the number of d-orbitals that are at a higher energy level and the number of d-orbitals that are at a lower energy level in **each** Co^{2+} ion.

number of d-orbitals at a higher energy level	
number of d-orbitals at a lower energy level	

[1]

(iii) Co^{2+} ions form a different complex ion, **M**.

Each **M** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated, but the ligands are different from the ligands in **G**.

Explain why **G** and **M** have different colours.

....

....

....

....

....

.... [2]

(c) Cadmium forms complex ion **X**, $[Cd(NH_3)_4]^{2+}$.

When a solution containing CN^- ions is added to an aqueous solution of **X**, a ligand exchange reaction takes place, forming complex ion **Y**. **Y** contains no NH_3 ligands and no H_2O ligands.

Y is in a much higher concentration in the mixture than **X**.

The oxidation state and coordination number of cadmium do **not** change in this reaction.

(i) Write an ionic equation for this reaction, using the formulae of the complex ions.

.... [2]

(ii) Cadmium forms complex ion **Z** in the same oxidation state and with the same coordination number as in **X**. All the ligands in **Z** are Cl^- ions.

When NaCl(aq) is added to a solution of **X**, very little **Z** forms.

Write the **three** cadmium complexes, **X**, **Y** and **Z**, in order of increasing stability constant, K_{stab}.

....	....	....
smallest value of K_{stab}		largest value of K_{stab}

[1]

(d) Ethanedioate ions, $C_2O_4^{2-}$, form complexes with transition element ions.

The concentration of $C_2O_4^{2-}$ ions can be found by reaction with acidified $Cr_2O_7^{2-}$ ions. $C_2O_4^{2-}$ ions are protonated and form HOOCCOOH molecules which are oxidised by $Cr_2O_7^{2-}$.

The half-equations are shown.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$$

$$2CO_2 + 2H^+ + 2e^- \rightleftharpoons HOOCCOOH$$

(i) Construct an equation for the reaction between acidified $Cr_2O_7^{2-}$ and HOOCCOOH.

.... [1]

(ii) A 25.0 cm^3 sample of a solution of $Na_2C_2O_4$ reacts with exactly 16.20 cm^3 of an acidified solution of 0.0500 $mol\,dm^{-3}$ $K_2Cr_2O_7$.

Calculate the concentration of the solution of $Na_2C_2O_4$.

$[Na_2C_2O_4]$ = ... $mol\,dm^{-3}$ [2]

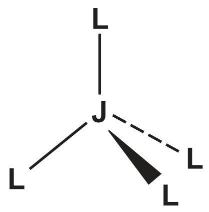
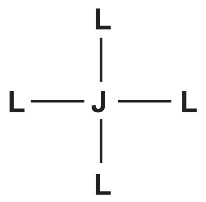
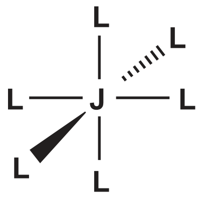
[Total: 12]

5 The shapes of four different complexes, **P**, **Q**, **R** and **S**, are shown in Table 5.1.

The symbol **J** represents an atom or ion of a transition element.

The symbol **L** is used to represent a monodentate ligand.

Table 5.1

P	**Q**
	
R	**S**
	

(a) Label **one** bond angle on **each** of complexes **P**, **Q**, **R** and **S**, and identify the size of the angle in degrees. [2]

(b) Identify the shapes of complexes **P**, **Q**, **R** and **S**.

P ....

Q ....

R ....

S ....

[2]

(c) Two **L** ligands are exchanged with two **different** monodentate ligands **X** and **Y** in each of complexes **P**, **Q**, **R** and **S**.

Identify all the complexes which form new complexes that show geometrical isomerism.

.... [1]

(d) Three **L** ligands are exchanged with three **different** monodentate ligands **X**, **Y** and **Z** in each of complexes **P**, **Q** and **R**.

Identify all the complexes which form new complexes that show optical isomerism.

.... [1]

[Total: 6]

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6 Benzene, C_6H_6, reacts with chloroethane, C_2H_5Cl, in the presence of a suitable catalyst to form ethylbenzene, $C_6H_5C_2H_5$. In the presence of the catalyst, the ion $C_2H_5^+$ is formed. This ion reacts with benzene.

(a) Complete the equation for the reaction of C_2H_5Cl with this catalyst to form $C_2H_5^+$ as one product.

C_2H_5Cl + ... → $C_2H_5^+$ + ... [1]

(b) Ethylbenzene reacts with more C_2H_5Cl, forming a mixture containing 1,2-diethylbenzene and 1,4-diethylbenzene.

(i) Draw the structures of 1,2-diethylbenzene and 1,4-diethylbenzene.

1,2-diethylbenzene	1,4-diethylbenzene

[1]

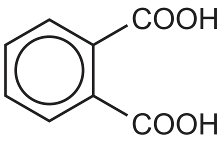
(ii) Explain why there is very little 1,3-diethylbenzene in the product mixture.

....

.... [1]

(c) 1,2-diethylbenzene can be oxidised to benzene-1,2-dioic acid, $C_6H_4(COOH)_2$.

benzene-1,2-dioic acid



(i) State the reagent and conditions used for this reaction.

.... [1]

(ii) Complete the overall equation for this reaction.

An atom of oxygen from the oxidising agent is represented as [O].

All of the atoms in the two ethyl groups are fully oxidised in this reaction.

.... + ... [O] → $C_6H_4(COOH)_2$ + ... + ...
(1,2-diethylbenzene)

[2]

(iii) Predict the number of peaks in the carbon-13 NMR spectrum of benzene-1,2-dioic acid.

.... [1]

(d) The proton (^1H) NMR spectra of ethylbenzene, $C_6H_5C_2H_5$, in $CDCl_3$ and of benzene-1,2-dioic acid, $C_6H_4(COOH)_2$, in $CDCl_3$ are shown. They have **not** been identified.

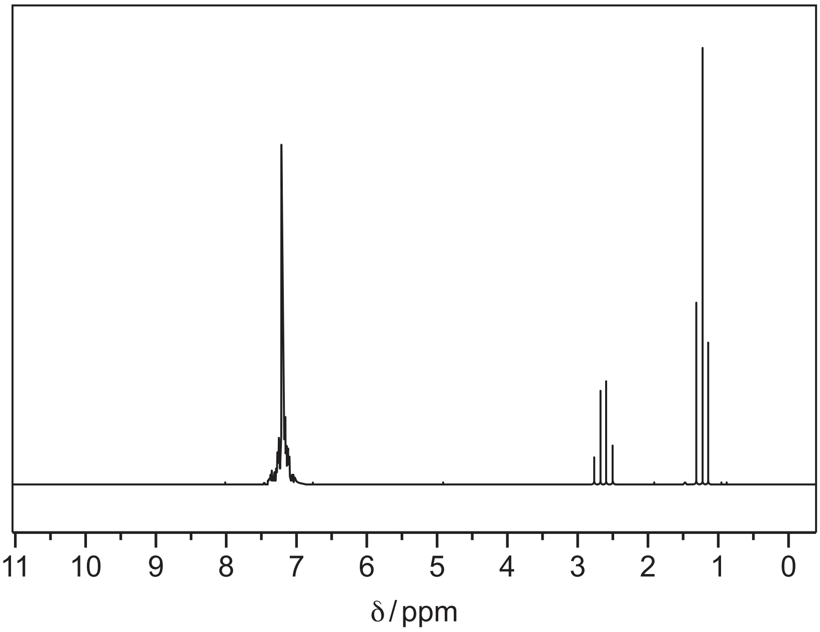


Fig. 6.1

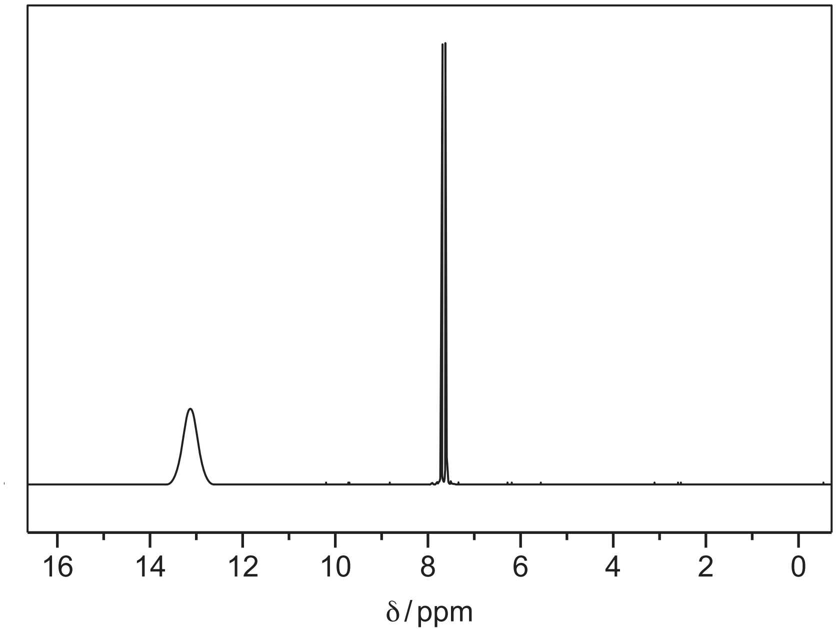


Fig. 6.2

(i) Explain the use of $CDCl_3$, instead of $CHCl_3$, as the solvent when obtaining these spectra.

.... [1]

(ii) Identify the substance shown by the spectrum in Fig. 6.1, and complete Table 6.1.

substance ....

Table 6.1

	peak at δ = 1.2	peak at δ = 2.6
name of splitting pattern		
group responsible for peak		
explanation of splitting pattern		

[3]

(iii) Identify the substance shown by the spectrum in Fig. 6.2, and complete Table 6.2.

substance ....

Table 6.2

	peak at δ = 7.8	peak at δ = 13.1
group responsible for peak		

[1]

(iv) When D_2O is used as a solvent, the spectrum obtained is different from the spectrum in Fig. 6.2.

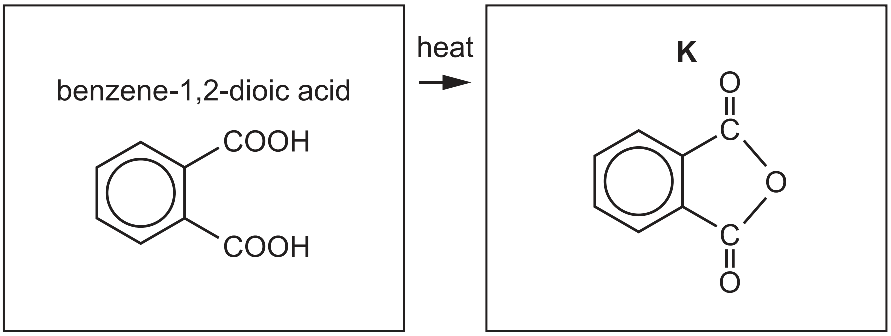
Describe this difference and explain your answer.

....

....

.... [1]

(e) Benzene-1,2-dioic acid can be used to produce **K**.



Suggest the name of this type of reaction.

.... [1]

[Total: 14]

7 A reaction scheme is shown in Fig. 7.1.

The reagents needed for reaction 2 and reaction 3 are stated.

Reaction 5 takes place when $C_2H_5NH_2$ is mixed with compound **V**. No special conditions are required.

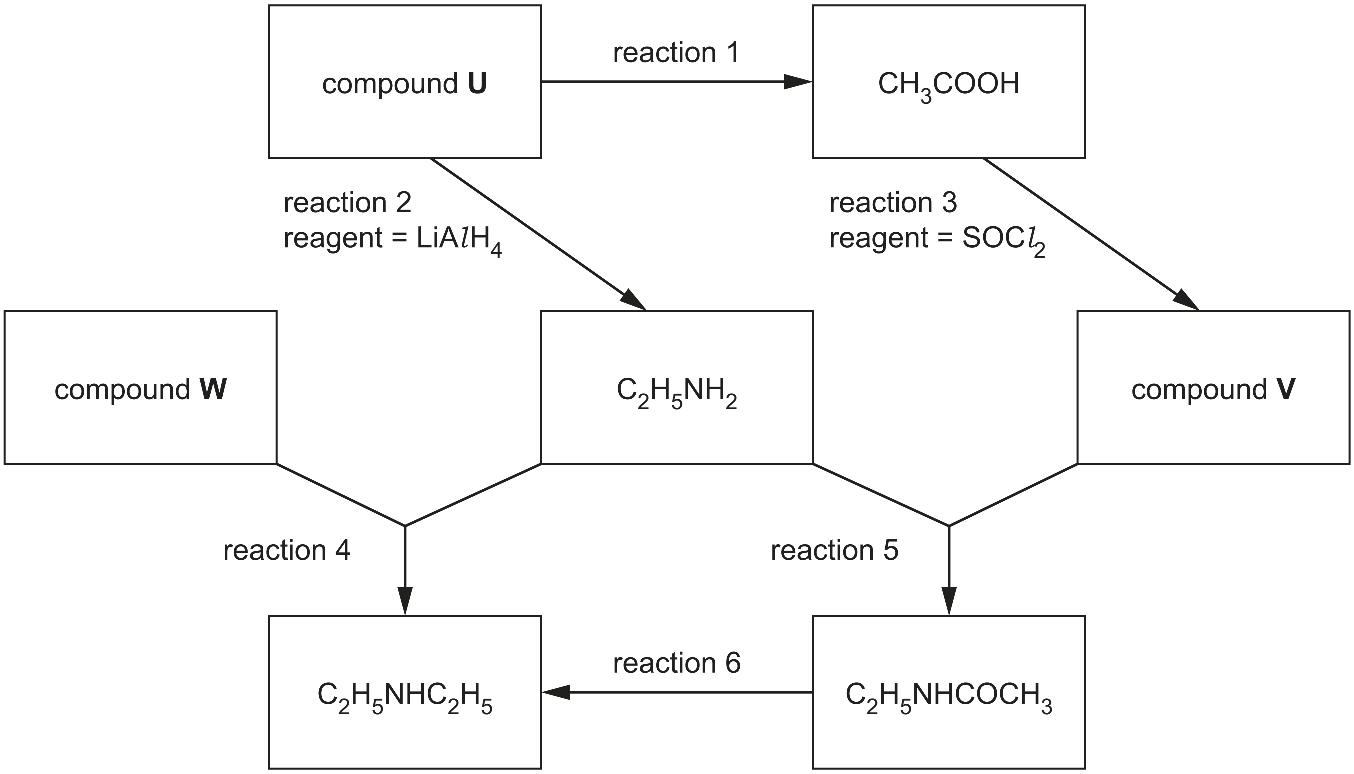


Fig. 7.1

(a) Identify compound **U** which contains only three elements.

.... [1]

(b) Describe the reagents and conditions for reaction 1.

.... [1]

(c) Identify compound **V**.

.... [1]

(d) Complete the equation for reaction 3.

$CH_3COOH + SOCl_2 \rightarrow$ .... [1]

(e) Identify compound **W**.

.... [1]

(f) Describe the conditions for reaction 4.

.... [1]

(g) Suggest the reagent needed for reaction 6.

.... [1]

(h) Complete Table 7.1 by adding the reaction numbers, 1, 2, 3, 4, 5 and 6, to the right-hand column. Use the reaction numbers given in Fig. 7.1.

Each of the numbers 1, 2, 3, 4, 5 and 6 should be used once only.

Table 7.1

type of reaction	reaction number(s)
hydrolysis	
addition	
reduction	
substitution	

[4]

(i) Compare the basicities of $C_2H_5NHCOCH_3$, $C_2H_5NHC_2H_5$ and NH_3.

Explain your answer.

....
most basic least basic

....

....

....

....

....

....
[4]

[Total: 15]

8 **(a)** An aqueous solution of phenol, C_6H_5OH, is acidic at 298 K.

Explain why phenol is more acidic than water.

....

....

.... [2]

(b) **(i)** Name the **two** products formed when phenol reacts with an excess of Br_2(aq).

.... and .... [1]

(ii) Draw the structures of the **two** isomeric organic products, with M_r = 139, that are formed when phenol reacts with HNO_3(aq) at room temperature.

[1]

(iii) Write the equation for the reaction between phenol, C_6H_5OH, and sodium metal.

.... [1]

(c) Phenol can be produced from phenylamine in a two-step synthesis.

$$\text{phenylamine} \xrightarrow{\text{step one}} \text{intermediate compound} \xrightarrow{\text{step two}} \text{phenol}$$

Describe the reagents and conditions needed in each step.

step one:

reagents ....

conditions ....

step two:

reagents ....

conditions ....

[2]

[Total: 7]

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Important values, constants and standards

molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Faraday constant	$F = 9.65 \times 10^{4}\,\mathrm{C\,mol^{-1}}$
Avogadro constant	$L = 6.022 \times 10^{23}\,\mathrm{mol^{-1}}$
electronic charge	$e = -1.60 \times 10^{-19}\,\mathrm{C}$
molar volume of gas	$V_m = 22.4\,\mathrm{dm^3\,mol^{-1}}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,\mathrm{dm^3\,mol^{-1}}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,\mathrm{mol^2\,dm^{-6}}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,\mathrm{kJ\,kg^{-1}\,K^{-1}}$ ($4.18\,\mathrm{J\,g^{-1}\,K^{-1}}$)

The Periodic Table of Elements

Group																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0			**Key** atomic number atomic symbol name relative atomic mass								5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

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