



Cambridge International AS & A Level

CANDIDATE NAME



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CHEMISTRY

9701/41

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.





1 (a) Disodium phosphate, $(\text{Na}^+)_2(\text{HPO}_4^{2-})$, reacts with an acid to form monosodium phosphate, $\text{Na}^+(\text{H}_2\text{PO}_4^-)$.

(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 $(\text{Na}^+)_2(\text{HPO}_4^{2-})$ and $\text{Na}^+(\text{H}_2\text{PO}_4^-)$ 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 $0.123 \text{ mol dm}^{-3}$.

..... [2]

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

..... [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 $1.40 \times 10^{-4} \text{ mol dm}^{-3}$ at 298 K.

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

$K_{sp} = \dots\dots\dots \text{ units } \dots\dots\dots [3]$

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

.....
.....
.....
.....
.....
.....
.....
.....
..... [3]

[Total: 16]



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- 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 .

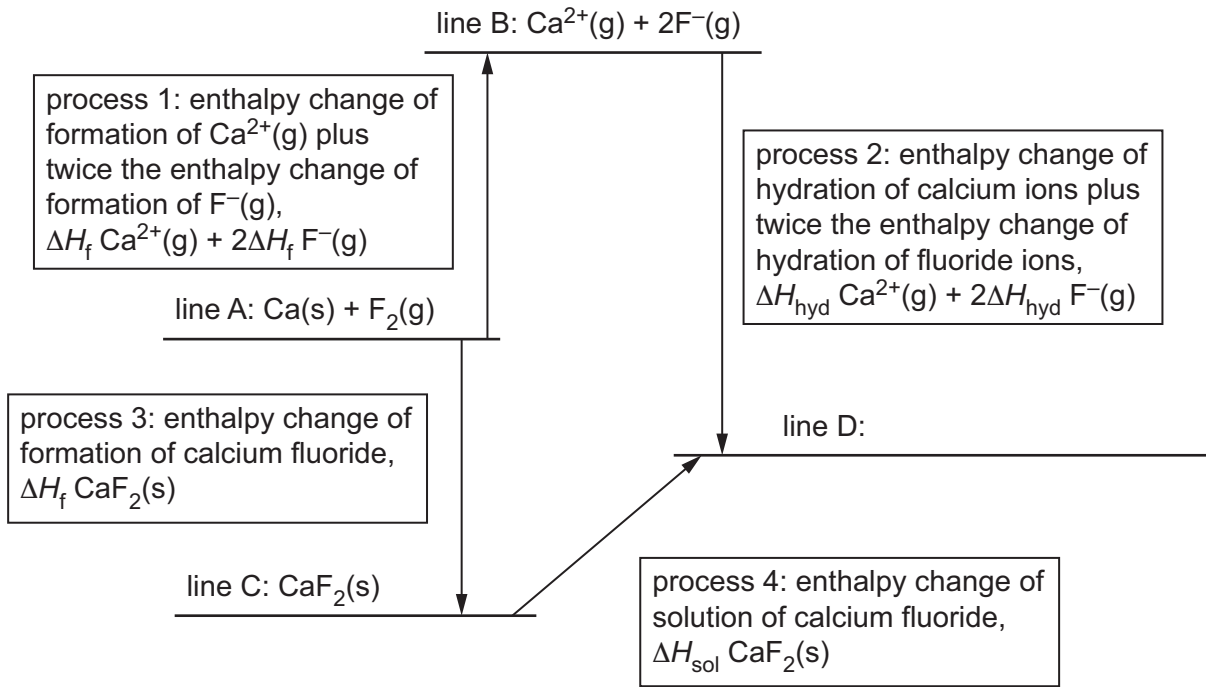
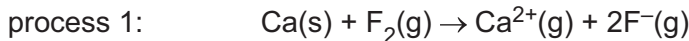


Fig. 2.1

- (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.



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.

$\Delta H_{\text{latt}} =$

[1]

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

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

$\Delta H_{\text{hyd}} \text{F}^-(\text{g}) = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

(d) Define entropy.

.....

..... [1]

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- (e) At 298 K, the Gibbs free energy change, ΔG , for the solution of compound **T** is $+6.00 \text{ kJ mol}^{-1}$.
 The enthalpy change of solution, ΔH_{sol} , of compound **T** is $+30.0 \text{ kJ mol}^{-1}$ at 298 K.
 Calculate the value of the entropy change, ΔS , for the solution of compound **T** at 298 K.

$\Delta S = \dots\dots\dots \text{ JK}^{-1} \text{ mol}^{-1}$ [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]

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



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

(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 .

$k = \dots\dots\dots$ units $\dots\dots\dots$ [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]

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(b) Catalysts may be homogeneous or heterogeneous.

(i) Identify **two** metals that act as heterogeneous catalysts in the removal of NO₂ 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) Fe²⁺ ions act as a homogeneous catalyst in the reaction between I⁻(aq) and S₂O₈²⁻(aq).

Write equations for the **two** reactions that occur when Fe²⁺(aq) is added to a mixture of I⁻(aq) and S₂O₈²⁻(aq).

equation 1 S₂O₈²⁻ +

equation 2 [2]

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

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

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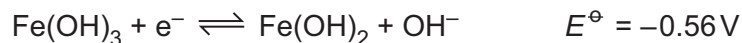


(c) Fe^{2+} ions can be oxidised to Fe^{3+} ions under alkaline conditions by suitable oxidising agents.

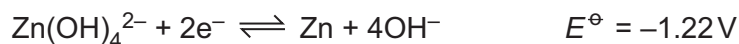
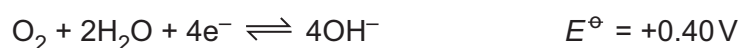
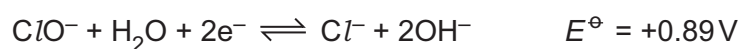
(i) Iron is a transition element. Explain why iron forms stable compounds in both the +2 and the +3 oxidation states.

..... [1]

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



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



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

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

oxidising agent 1:

equation:

$$E_{\text{cell}}^\ominus = \dots\dots\dots \text{V}$$

oxidising agent 2:

equation:

$$E_{\text{cell}}^\ominus = \dots\dots\dots \text{V}$$

[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]

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- (c) Cadmium forms complex ion **X**, $[\text{Cd}(\text{NH}_3)_4]^{2+}$.

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 $\text{NaCl}(\text{aq})$ is added to a solution of **X**, very little **Z** forms.

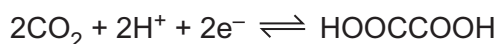
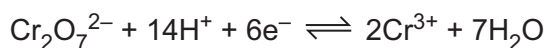
Write the **three** cadmium complexes, **X**, **Y** and **Z**, in order of increasing stability constant, K_{stab} .

.....
 smallest value of K_{stab} largest value of K_{stab} [1]

- (d) Ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, form complexes with transition element ions.

The concentration of $\text{C}_2\text{O}_4^{2-}$ ions can be found by reaction with acidified $\text{Cr}_2\text{O}_7^{2-}$ ions. $\text{C}_2\text{O}_4^{2-}$ ions are protonated and form HOCCOOH molecules which are oxidised by $\text{Cr}_2\text{O}_7^{2-}$.

The half-equations are shown.



- (i) Construct an equation for the reaction between acidified $\text{Cr}_2\text{O}_7^{2-}$ and HOCCOOH .

..... [1]

- (ii) A 25.0 cm^3 sample of a solution of $\text{Na}_2\text{C}_2\text{O}_4$ reacts with exactly 16.20 cm^3 of an acidified solution of $0.0500\text{ mol dm}^{-3}$ $\text{K}_2\text{Cr}_2\text{O}_7$.

Calculate the concentration of the solution of $\text{Na}_2\text{C}_2\text{O}_4$.

$[\text{Na}_2\text{C}_2\text{O}_4] = \dots\dots\dots\text{ mol dm}^{-3}$ [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>P</p>	<p>Q</p>
<p>R</p>	<p>S</p>

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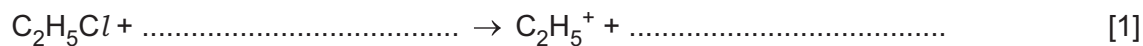
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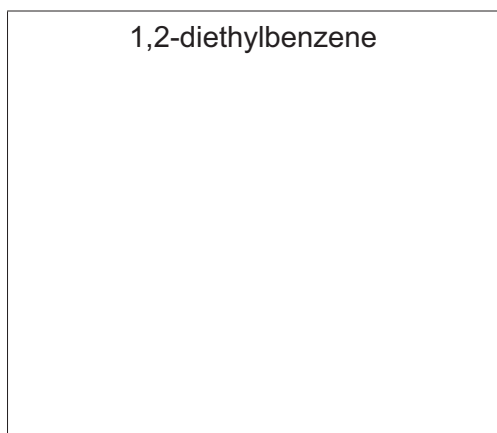
- 6 Benzene, C_6H_6 , reacts with chloroethane, C_2H_5Cl , in the presence of a suitable catalyst to form ethylbenzene, $C_6H_5C_2H_5$. In the presence of the catalyst, the ion $C_2H_5^+$ is formed. This ion reacts with benzene.

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



- (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]

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

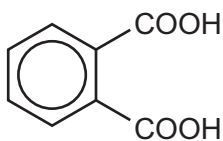
.....
 [1]





(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] \rightarrow $C_6H_4(COOH)_2$ + +
(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, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$, in CDCl_3 and of benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$, in CDCl_3 are shown. They have **not** been identified.

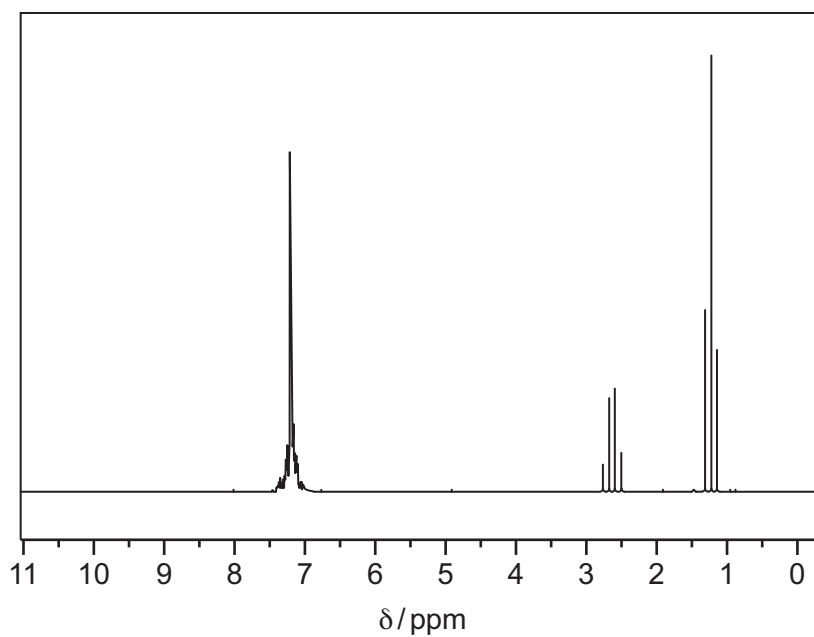


Fig. 6.1

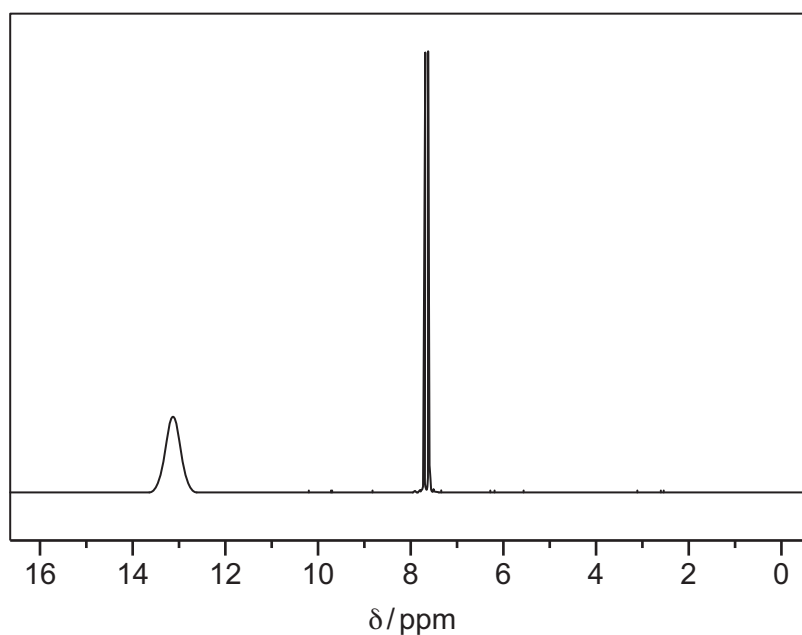


Fig. 6.2

- (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 $\delta = 1.2$	peak at $\delta = 2.6$
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 $\delta = 7.8$	peak at $\delta = 13.1$
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.

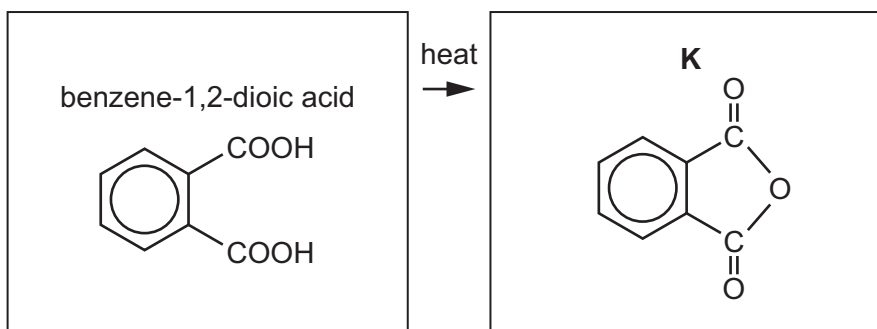
Describe this difference and explain your answer.

.....

.....

..... [1]

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



Suggest the name of this type of reaction.

..... [1]





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.

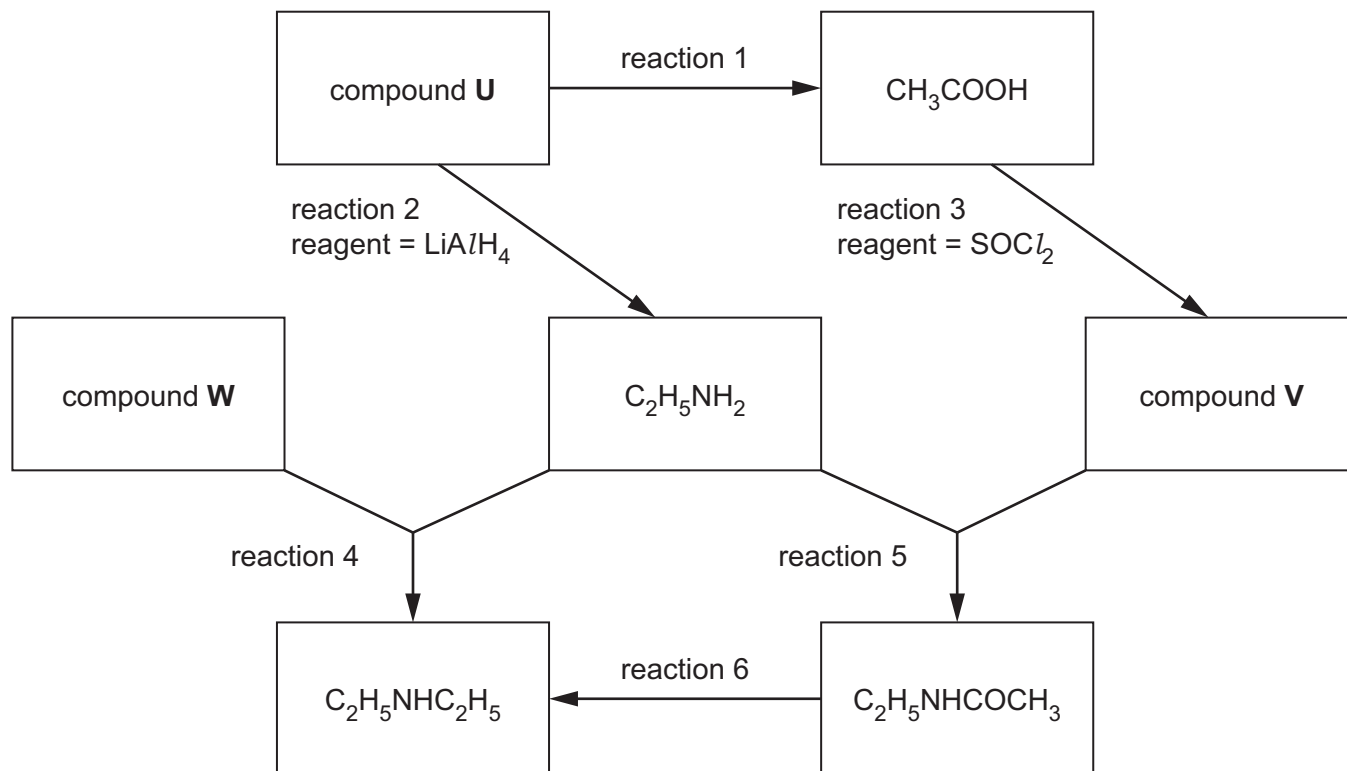


Fig. 7.1

(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]



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- 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.



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	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 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																																																																									
		<table border="1" style="margin: auto;"> <tr> <td>1</td> <td>H</td> <td>hydrogen</td> <td>1.0</td> </tr> </table>																1	H	hydrogen	1.0																																																																					
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Key	atomic number	atomic symbol	name	relative atomic mass																																																																																						
3	Li	Li	lithium	6.9	4	Be	beryllium	9.0	11	Na	Na	sodium	23.0	12	Mg	Mg	magnesium	24.3	13	B	B	boron	10.8	14	C	C	carbon	12.0	15	N	N	nitrogen	14.0	16	O	O	oxygen	16.0	17	F	F	fluorine	19.0	18	Ne	Ne	neon	20.2																																										
19	K	K	potassium	39.1	20	Ca	calcium	40.1	21	Sc	Sc	scandium	45.0	22	Ti	Ti	titanium	47.9	23	V	V	vanadium	50.9	24	Cr	Cr	chromium	52.0	25	Mn	Mn	manganese	54.9	26	Fe	Fe	iron	55.8	27	Co	Co	cobalt	58.9	28	Ni	Ni	nickel	58.7	29	Cu	Cu	copper	63.5	30	Zn	Zn	zinc	65.4	31	Ga	Ga	gallium	69.7	32	Ge	Ge	germanium	72.6	33	As	As	arsenic	74.9	34	Se	Se	selenium	79.0	35	Br	Br	bromine	79.9	36	Kr	Kr	krypton	83.8		
37	Rb	Rb	rubidium	85.5	38	Sr	strontium	87.6	39	Y	Y	yttrium	88.9	40	Zr	Zr	zirconium	91.2	41	Nb	Nb	niobium	92.9	42	Mo	Mo	molybdenum	95.9	43	Tc	Tc	technetium	—	44	Ru	Ru	ruthenium	101.1	45	Rh	Rh	rhodium	102.9	46	Pd	Pd	palladium	106.4	47	Ag	Ag	silver	107.9	48	Cd	Cd	cadmium	112.4	49	In	In	indium	114.8	50	Sn	Sn	tin	118.7	51	Sb	Sb	antimony	121.8	52	Te	Te	tellurium	127.6	53	I	I	iodine	126.9	54	Xe	Xe	xenon	131.3		
55	Cs	Cs	caesium	132.9	56	Ba	barium	137.3	57–71	lanthanoids						72	Hf	Hf	hafnium	178.5	73	Ta	Ta	tantalum	180.9	74	W	W	tungsten	183.8	75	Re	Re	rhenium	186.2	76	Os	Os	osmium	190.2	77	Ir	Ir	iridium	192.2	78	Pt	Pt	platinum	195.1	79	Au	Au	gold	197.0	80	Hg	Hg	mercury	200.6	81	Tl	Tl	thallium	204.4	82	Pb	Pb	lead	207.2	83	Bi	Bi	bismuth	209.0	84	Po	Po	polonium	—	85	At	At	astatine	—	86	Rn	Rn	radon	—
87	Fr	Fr	francium	—	88	Ra	radium	—	89–103	actinoids						104	Rf	Rf	rutherfordium	—	105	Db	Db	dubnium	—	106	Sg	Sg	seaborgium	—	107	Bh	Bh	bohrium	—	108	Hs	Hs	hassium	—	109	Mt	Mt	meitnerium	—	110	Ds	Ds	darmstadtium	—	111	Rg	Rg	roentgenium	—	112	Cn	Cn	coppernium	—	113	Nh	Nh	nihonium	—	114	Fl	Fl	flerovium	—	115	Mc	Mc	moscovium	—	116	Lv	Lv	livermorium	—	117	Ts	Ts	tennessine	—	118	Og	Og	oganeson	—

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

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