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Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME	

CENTRE NUMBER		CANDIDATE NUMBER	

* 0 1 4 9 5 2 0 5 6 0 *

CHEMISTRY **9701/42**

Paper 4 A Level Structured Questions **October/November 2025**

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.

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1 Magnesium nitrate, $Mg(NO_3)_2$, and strontium nitrate, $Sr(NO_3)_2$, both decompose when heated to form the metal oxide and a mixture of gases.

(a) Write an equation for the thermal decomposition of $Mg(NO_3)_2$.

.... [1]

(b) State which of $Mg(NO_3)_2$ or $Sr(NO_3)_2$ decomposes at a lower temperature.

Explain your answer.

compound that decomposes at a lower temperature ....

explanation ....

....

....

....

....

[2]

(c) Magnesium oxide, MgO, and strontium oxide, SrO, both react with dilute sulfuric acid.

MgO forms a soluble salt, **A**.

SrO forms an insoluble salt, **B**.

(i) Identify the products formed when MgO reacts with dilute sulfuric acid.

.... [1]

(ii) Explain why **A** is more soluble than **B**.

....

....

....

....

....

.... [3]

[Total: 7]

2 Ethanal, CH_3CHO, reacts with nitrogen dioxide, NO_2. The products of the first step of this reaction are a $CH_3\dot{C}{=}O$ radical and a molecule of nitrous acid, HNO_2.

$$CH_3CHO + NO_2 \rightarrow CH_3\dot{C}{=}O + HNO_2$$

(a) **(i)** Use **two** words to complete the sentence.

This reaction involves .... of the single covalent bond between a hydrogen atom and a carbon atom in CH_3CHO.

[1]

(ii) The hydrogen atom mentioned in **(a)(i)** forms a covalent bond with one of the oxygen atoms of an NO_2 molecule. An NO_2 molecule has a single, unpaired electron on the nitrogen atom. All electrons are paired in an HNO_2 molecule.

Draw dot-and-cross diagrams of NO_2 and HNO_2 in the boxes. Show outer shell electrons only.

NO_2	HNO_2

[1]

(iii) Use VSEPR theory to predict the bond angle at the nitrogen atom in an HNO_2 molecule.

bond angle = ... [1]

(b) The rate equation for the reaction between CH_3CHO and NO_2 is shown.

$$\text{rate} = k[CH_3CHO][NO_2]$$

Under certain conditions, when the concentrations of both CH_3CHO and NO_2 are $0.200\,mol\,dm^{-3}$, the rate of the reaction is $1.53 \times 10^{-4}\,mol\,dm^{-3}\,s^{-1}$.

Calculate the value of the rate constant, k, under these conditions. Give the units of k.

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

(c) The reaction mixture described in **(b)** is monitored over a period of time.

Predict whether the graph of $[NO_2]$ against time shows a constant half-life.

Explain your answer.

prediction ....

explanation ....

.... [1]

(d) NO_2 also reacts with ozone, O_3.

The rate equation is shown.

$$\text{rate} = k_1[NO_2]$$

Under certain conditions, the value of k_1 is $0.0848\,s^{-1}$.

The reaction has a constant half-life under these conditions.

Calculate the half-life in seconds.

half-life = ... s [1]

(e) NO_2 is present in the exhaust gases of cars. It can react with carbon monoxide, CO, on the surface of a heterogeneous catalyst in the car's catalytic converter.

Describe the mode of action of this heterogeneous catalyst.

....

....

....

....

....

.... [2]

[Total: 9]

3 (a) (i) Define conjugate acid–base pair.

....

.... [1]

(ii) Give the formulas of the conjugate acid and the conjugate base of the hydrogen phosphate ion, HPO_4^{2-}.

conjugate acid of HPO_4^{2-} ....

conjugate base of HPO_4^{2-} ....
[1]

(b) The K_a of propanoic acid, CH_3CH_2COOH, is 1.35×10^{-5} mol dm^{-3} at 298 K.

Solution **C** is a solution of CH_3CH_2COOH with a pH of 3.60 at 298 K.

(i) Calculate the concentration of CH_3CH_2COOH in solution **C**.

$[CH_3CH_2COOH]$ = ... mol dm^{-3} [2]

(ii) Calculate the concentration of hydroxide ions in solution **C**.

$[OH^-]$ = ... mol dm^{-3} [1]

(iii) Calculate the concentration of a solution of hydrochloric acid with the same pH as solution **C**.

concentration = ... mol dm^{-3} [1]

(iv) Table 3.1 shows three possible values of the K_a of dimethylpropanoic acid, $(CH_3)_3CCOOH$.

Place a tick in Table 3.1 to show the correct value. Explain your answer.

Table 3.1

value of K_a / $mol\,dm^{-3}$	place **one** tick (✓) in this column
9.33×10^{-6}	
1.35×10^{-5}	
3.35×10^{-5}	

explanation ....

....

....

....

.... [3]

(c) Solution **D** is made by mixing $100\,cm^3$ of $0.100\,mol\,dm^{-3}$ CH_3CH_2COOH and $100\,cm^3$ of $0.100\,mol\,dm^{-3}$ $NaCl$.

The pH of solution **D** is measured as small amounts of $H_2SO_4(aq)$ are added to it, and when small amounts of NaOH(aq) are added to it.

Solution **D** only acts as a buffer solution when **one** of these solutions is added to it.

(i) Complete the sentence and write an equation for the reaction that occurs.

Solution **D** acts as a buffer when .... is added to it.

equation ....
[1]

(ii) Complete the sentence and explain why solution **D** does **not** act as a buffer when the other solution is added.

Solution **D** does **not** act as a buffer when .... is added to it.

explanation ....

....
[1]

(d) Manganese(II) hydroxide, $Mn(OH)_2$, is only slightly soluble in water.

The solubility of $Mn(OH)_2$ in water is $3.28 \times 10^{-3}\,g\,dm^{-3}$ at 298 K.

(i) Calculate the concentration of a saturated solution of $Mn(OH)_2$ at 298 K.

$[Mn(OH)_2]$ = ... $mol\,dm^{-3}$ [1]

(ii) Write an expression for the K_{sp} of $Mn(OH)_2$. Give the units of K_{sp}.

K_{sp} =

units = ...

[2]

(iii) Use your answers to **(d)(i)** and **(d)(ii)** to calculate the value of K_{sp} of $Mn(OH)_2$ at 298 K.

K_{sp} = ... [1]

[Total: 15]

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DO NOT WRITE IN THIS MARGIN

4 **(a)** Define enthalpy change of atomisation, ΔH_{at}.

....

.... [1]

(b) Define first electron affinity, EA.

....

.... [1]

(c) Explain why the first electron affinity of chlorine is more exothermic than the first electron affinity of iodine.

....

....

....

.... [2]

(d) The enthalpy change for the reaction $Cl_2(g) + 2e^- \rightarrow 2Cl^-(g)$ is $-486\,kJ\,mol^{-1}$.

The first electron affinity of chlorine is $-364\,kJ\,mol^{-1}$.

Calculate the enthalpy change of atomisation of chlorine.

ΔH_{at} of chlorine = ... $kJ\,mol^{-1}$ [2]

[Total: 6]

5 Cobalt is a transition element which forms compounds containing Co^{2+} and Co^{3+} ions. Cobalt(II) sulfate dissolves in water to form a solution containing the $[Co(H_2O)_6]^{2+}$ complex ion.

(a) **(i)** Complete the electronic configurations of a Co^{2+} ion and a Co^{3+} ion.

Co^{2+} = [Ar] ....

Co^{3+} = [Ar] ....

[1]

(ii) Explain why transition elements can form complex ions.

....

.... [1]

(iii) An excess of concentrated HCl is added to a solution containing $[Co(H_2O)_6]^{2+}$.

Describe the colour change observed and the state of the cobalt-containing product.

The colour changes from .... to ....

The state of the cobalt-containing product is ....

[2]

(iv) Write an equation for the reaction occurring in **(a)(iii)**.

.... [1]

(v) Name the type of reaction occurring in **(a)(iii)**.

.... [1]

(vi) Write an equation for the reaction that occurs when an excess of NaOH(aq) is added to a solution containing $[Co(H_2O)_6]^{2+}$.

.... [1]

(b) Cobalt metal can be oxidised by acidified $K_2Cr_2O_7$. The relevant half-equations, and their $E^\ominus$ values, are shown.

$$Co^{2+} + 2e^- \rightleftharpoons Co \qquad E^\ominus = -0.28\,V$$
$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O \qquad E^\ominus = +1.33\,V$$

(i) A Co^{2+}/Co electrode is constructed in which $[Co^{2+}]$ is $0.020\,mol\,dm^{-3}$ at 298 K.

Use the Nernst equation to show that the E value for this Co^{2+}/Co electrode is –0.33 V.

[2]

(ii) An electrochemical cell is constructed using the Co^{2+}/Co electrode described in **(b)(i)** and a $Cr_2O_7^{2-}/Cr^{3+}$ electrode in which all conditions are standard.

Calculate the value of E_{cell}.

E_{cell} = ... [1]

(iii) A current is drawn from the electrochemical cell described in **(b)(ii)**.

Write an equation for the reaction taking place in the cell.

.... [1]

(iv) Complete the sentences to identify the negative electrode and the direction of electron flow when a current is drawn from the cell described in **(b)(ii)**.

The .... electrode is the negative electrode.

Electrons flow from the .... electrode to the .... electrode.
[1]

(c) A molten Co^{2+} salt is electrolysed using a current of 0.500 A.

0.547 g of cobalt metal forms at the cathode. Under the conditions used no other reduction reaction occurs at the cathode.

Calculate the time in minutes for which the current flows to produce this mass of cobalt.

Give your answer to **three** significant figures.

time = ... min [3]

[Total: 15]

6 (a) Nickel forms complexes.

(i) Give the formula and charge of the tetrahedral complex formed by Ni atoms with carbon monoxide molecules. Carbon monoxide is a monodentate ligand. This is complex **E**.

E = ... [1]

(ii) Give the formula and charge of the octahedral complex formed by Ni^{2+} ions with ethanedioate ions. This is complex **F**.

F = ... [2]

(iii) Identify which complex, **E** or **F**, exists as a mixture of two stereoisomers and the type of stereoisomerism involved.

The complex which exists as a mixture of two stereoisomers is ....

The type of stereoisomerism involved is ....

[1]

(b) Cadmium forms complexes with methylamine, CH_3NH_2, and 1,2-diaminoethane, *en*. The values of the stability constants, K_{stab}, of these complex ions are given in Table 6.1.

Table 6.1

complex	K_{stab}
$[Cd(CH_3NH_2)_4]^{2+}$	3.5×10^6
$[Cd(en)_2]^{2+}$	4.0×10^{10}

(i) Explain, by reference to its structure, why CH_3NH_2 acts as a monodentate ligand.

.... [1]

(ii) Some Cd^{2+}(aq) is added to a solution containing equal concentrations of CH_3NH_2 and *en*.

Predict which of the two complexes in Table 6.1 forms at the higher concentration.

Explain your answer.

complex that forms at the higher concentration ....

explanation ....

....

[1]

(iii) Complete the expression for the K_{stab} of $[Cd(CH_3NH_2)_4]^{2+}$.

K_{stab} =

[1]

[Total: 7]

7 **P**, **Q**, **R**, **S**, **T**, **U**, and **V** are the seven structural isomers with molecular formula $C_5H_{10}O$ that have a carbonyl group.

P $CH_3(CH_2)_3CHO$ **Q** $CH_3CH_2CH(CH_3)CHO$ **R** $(CH_3)_2CHCH_2CHO$

S $(CH_3)_3CCHO$ **T** $CH_3CH_2CH_2COCH_3$ **U** $CH_3CH_2COCH_2CH_3$

V $(CH_3)_2CHCOCH_3$

(a) Only one of these seven compounds has stereoisomers.

Draw three-dimensional diagrams of the **two** stereoisomers of this compound.

[2]

(b) **P**, **Q**, **R**, **S**, **T**, **U**, and **V** are treated separately with alkaline I_2(aq) and the product mixture is acidified.

(i) Identify the **two** compounds that give a positive result with alkaline I_2(aq).

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

(ii) Describe the observations when **one** of the compounds you have identified in **(b)(i)** is treated with alkaline I_2(aq) and give the structural formulae of the **two** carbon-containing products of this reaction.

observations ....

two carbon-containing products ....

and ....

[2]

P $CH_3(CH_2)_3CHO$ **Q** $CH_3CH_2CH(CH_3)CHO$ **R** $(CH_3)_2CHCH_2CHO$

S $(CH_3)_3CCHO$ **T** $CH_3CH_2CH_2COCH_3$ **U** $CH_3CH_2COCH_2CH_3$

V $(CH_3)_2CHCOCH_3$

(c) The proton (^1H) NMR spectra of **P**, **Q**, **R**, **S**, **T**, **U**, and **V** are compared.

(i) Identify the only compound that gives a spectrum with two singlets and no other peaks.

.... [1]

Fig. 7.1 shows the spectrum obtained from one of the compounds.

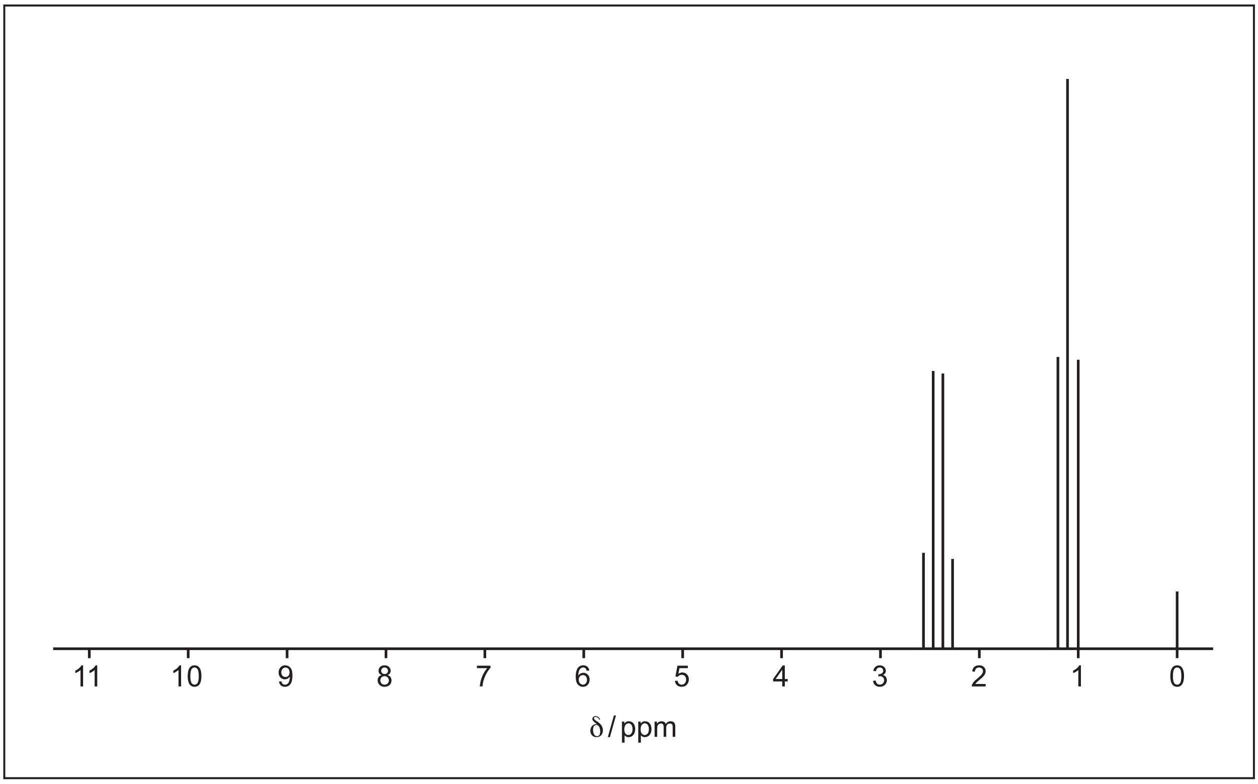


Fig. 7.1

(ii) Identify the compound that gives this spectrum.

.... [1]

(iii) Name the splitting pattern of the peak at δ = 1.1 in Fig. 7.1.

Give the reason for this splitting.

name ....

reason ....
[1]

(iv) Identify the substance that gives the small peak at δ = 0 in Fig. 7.1.

.... [1]

(d) The carbon-13 NMR spectra of **R**, **S**, **T** and **U** are compared.

Complete Table 7.1 to state the number of peaks in the spectrum of each compound.

Table 7.1

compound		number of peaks
R	$(CH_3)_2CHCH_2CHO$	
S	$(CH_3)_3CCHO$	
T	$CH_3CH_2CH_2COCH_3$	
U	$CH_3CH_2COCH_2CH_3$	

[2]

[Total: 11]

8 Asparagine and aspartic acid are two naturally occurring amino acids. Their structures and isoelectric points are shown in Table 8.1.

Table 8.1

amino acid	structure	isoelectric point
asparagine	$HOOCCH(NH_2)CH_2CONH_2$	5.41
aspartic acid	$HOOCCH(NH_2)CH_2COOH$	2.77

(a) Define isoelectric point.

....

.... [1]

(b) Draw the structures of asparagine and aspartic acid at pH 2.

asparagine at pH 2	aspartic acid at pH 2

[2]

(c) Asparagine and aspartic acid are treated separately with an excess of $LiAlH_4$.

Draw the structures of the organic products of these reactions.

product of asparagine treated with an excess of $LiAlH_4$	product of aspartic acid treated with an excess of $LiAlH_4$

[2]

(d) Propanedioic acid, $HOOCCH_2COOH$, is treated with an excess of thionyl chloride, $SOCl_2$. Propanedioyl chloride, $ClOCCH_2COCl$, is formed.

(i) Write an equation for this reaction.

.... [1]

(ii) Propanedioyl chloride reacts with an excess of asparagine to form compound **G** with molecular formula $C_{11}H_{16}N_4O_8$.

Each molecule of compound **G** has four amide groups.

Draw the structure of compound **G**.

Compound **G**, $C_{11}H_{16}N_4O_8$

[2]

(e) Asparagine is hydrolysed with an excess of hot NaOH(aq).

Draw the structure of the organic product of this reaction.

[2]

(f) A polymer can form from asparagine, $HOOCCH(NH_2)CH_2CONH_2$, as the only monomer.

Draw a length of the polymer chain containing **three** monomer residues.

Clearly label the repeat unit of the polymer on your diagram.

[3]

(g) Aspartic acid exists in two optically active forms.

(i) Plane polarised light is passed through pure samples of these two optically active forms in solutions of the same concentration.

Describe **two** similarities and **one** difference in their effect on the plane polarised light.

similarities ....

....

difference ....

....
[2]

(ii) Give the term used to describe a mixture of equal amounts of the two optically active forms.

.... [1]

[Total: 16]

Question 9 starts on page 20.

9 Compound **X** is made from benzene by the route shown in Fig. 9.1.

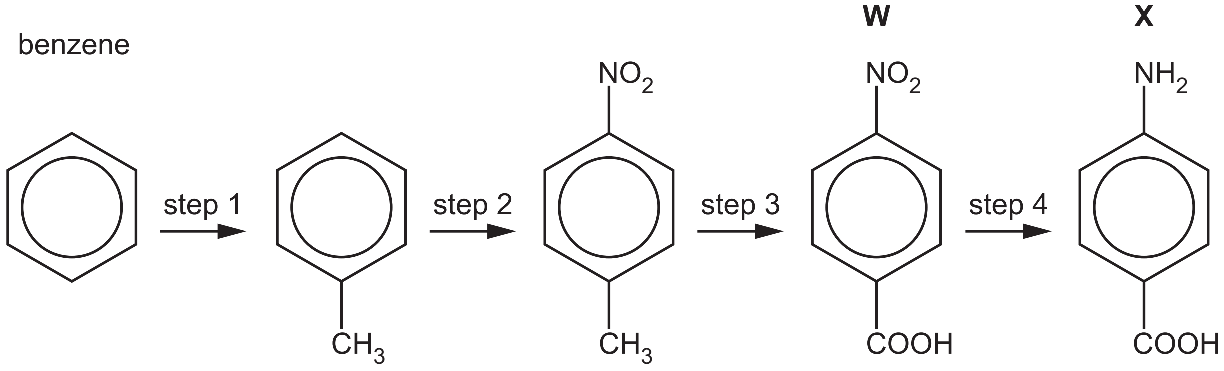


Fig. 9.1

(a) Describe the bonding in benzene, C_6H_6.

Your answer should include:

- the hybridisation of the six carbon atoms
- the types of bond between the carbon atoms
- the orbitals that overlap to produce the bonds between the carbon atoms
- the type of bond between the carbon atoms and the hydrogen atoms
- the orbitals that overlap to produce the bonds between the carbon atoms and the hydrogen atoms.

....

....

....

....

....

....

.... [3]

(b) Describe the reagents and conditions required for step 1 in Fig. 9.1.

....

.... [1]

(c) In step 1 of Fig. 9.1 benzene reacts with $^{+}CH_3$.

Complete Fig. 9.2 to show the mechanism for this reaction, including:

- the movement of electron pairs using curly arrows
- the structure of the intermediate involved.

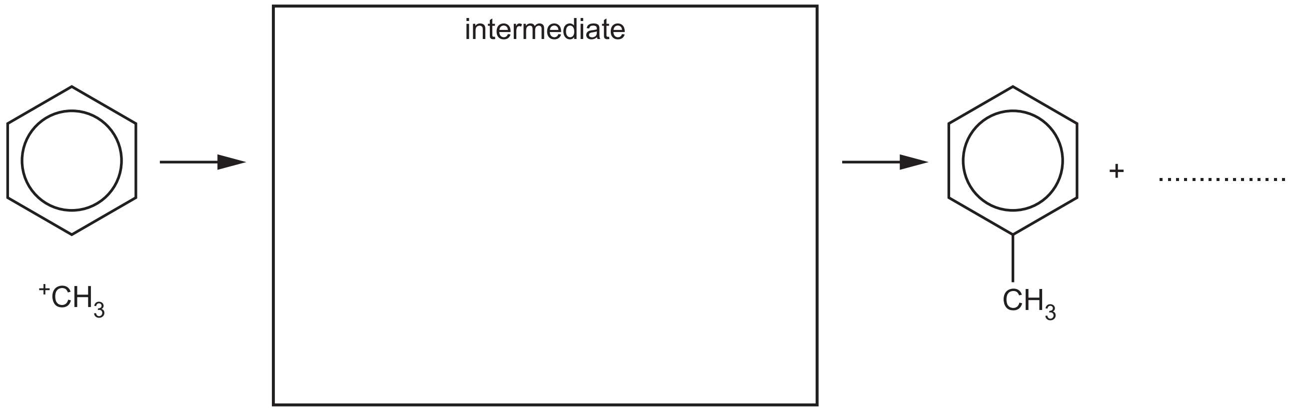


Fig. 9.2

[3]

(d) Describe the reagents and conditions required for step 2 of Fig. 9.1.

....

.... [2]

(e) Identify the reagents required for step 3 of Fig. 9.1. Compound **W** is the product of this step.

.... [1]

(f) Name compound **W**.

.... [1]

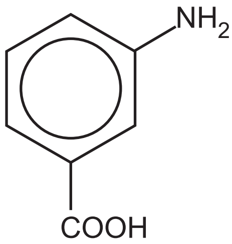
(g) The reagents commonly used for step 4 will **not** reduce the –COOH group.

Identify the reagents and conditions required for step 4 of Fig. 9.1.

.... [1]

(h) Benzene can also be used as a starting material to make compound **Y**.

compound **Y**



Describe how the route described in Fig. 9.1 (repeated below) can be changed to give compound **Y** instead of compound **X**.

Explain your answer.

....

....

....

.... [2]

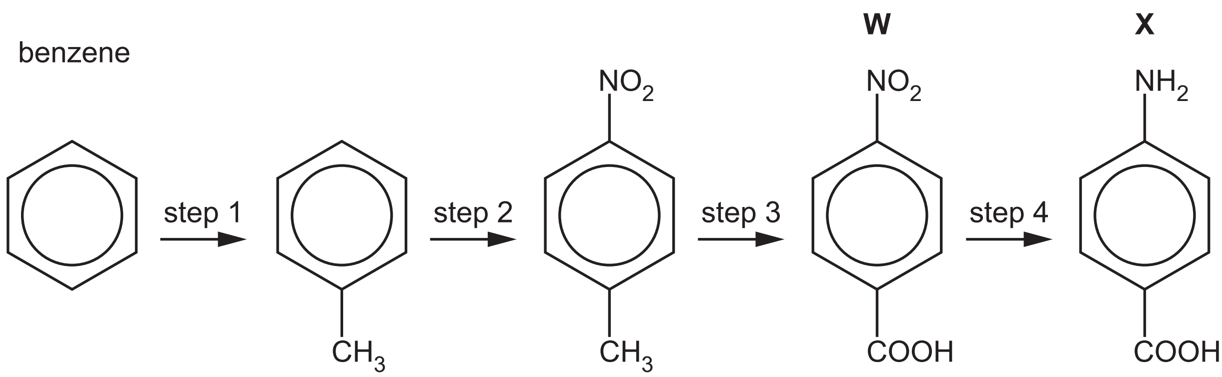


Fig. 9.1

[Total: 14]

Important values, constants and standards

molar gas constant	R = 8.31 J K^{-1} mol^{-1}
Faraday constant	F = 9.65 × 10^{4} C mol^{-1}
Avogadro constant	L = 6.02 × 10^{23} mol^{-1}
electronic charge	e = –1.60 × 10^{-19} C
molar volume of gas	V_m = 22.4 dm^{3} mol^{-1} at s.t.p. (101 kPa and 273 K) V_m = 24.0 dm^{3} mol^{-1} at room conditions
ionic product of water	K_w = 1.00 × 10^{-14} mol^{2} dm^{-6} (at 298 K (25 °C))
specific heat capacity of water	c = 4.18 kJ kg^{-1} K^{-1} (4.18 J g^{-1} K^{-1})

DFD

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

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											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 –