Cambridge Assessment International Education

# Cambridge International AS & A Level

CANDIDATE NAME

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*9281939058*

**CHEMISTRY** **9701/42**

Paper 4 A Level Structured Questions **February/March 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 **28** pages. Any blank pages are indicated.


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**1** Potassium iodide, KI, is used as a reagent in both inorganic and organic chemistry.

**(a)** KI forms an ionic lattice that is soluble in water.

**(i)** Define enthalpy change of solution, $\Delta H_{sol}$.

.....

.....

..... [1]

**(ii)** KI(s) has a high solubility in water although its enthalpy change of solution is endothermic.

Explain how this high solubility is possible.

.....

.....

..... [2]

**(b)** Table 1.1 gives some data about the halide ions, $Cl^-$, $Br^-$ and $I^-$, and their potassium salts.

**Table 1.1**

| halide ion | enthalpy change of hydration, $\Delta H_{hyd}$ / kJ mol$^{-1}$ | lattice energy of potassium halide, $\Delta H_{latt}$ / kJ mol$^{-1}$ |
|---|---|---|
| $Cl^-$ | –364 | –701 |
| $Br^-$ | –335 | –670 |
| $I^-$ | –293 | –629 |

**(i)** Explain the trend in the enthalpy change of hydration of the halide ions.

.....

.....

.....

..... [2]

**(ii)** The $\Delta H_{sol}$ values of these potassium halides are almost constant.

Use the $\Delta H_{hyd}$ and $\Delta H_{latt}$ data in Table 1.1 to suggest why.

.....

.....

..... [1]

**(iii)** The enthalpy change of solution of KI(s) is +21.0 kJ mol$^{-1}$.

Use this information and the data in Table 1.1 to calculate the enthalpy change of hydration of the potassium ion, $K^+(g)$.

$\Delta H_{hyd}$ of $K^+(g)$ = ..... kJ mol$^{-1}$ [1]

**(iv)** Solid $PbI_2$ forms when KI(aq) is mixed with $Pb^{2+}(aq)$ ions.

The solubility product, $K_{sp}$, of $PbI_2$ is $7.1 \times 10^{-9}$ mol$^3$ dm$^{-9}$ at 25 °C.

Calculate the solubility, in mol dm$^{-3}$, of $PbI_2(s)$.

solubility of $PbI_2(s)$ = ..... mol dm$^{-3}$ [2]

**(v)** The ionic radius of $Pb^{2+}$ is 0.120 nm compared to 0.133 nm for $K^+$.

Suggest how the $\Delta H^{\ominus}_{latt}$ of $PbI_2(s)$ differs from $\Delta H^{\ominus}_{latt}$ of KI(s).

Explain your answer.

.....

.....

..... [2]

**(c)** KI slowly oxidises in air, forming $I_2$.

reaction 1 $4KI(s) + 2CO_2(g) + O_2(g) \rightarrow 2K_2CO_3(s) + 2I_2(s)$ $\Delta H^{\ominus} = -203.4\,kJ\,mol^{-1}$

Table 1.2 shows some data relevant to this question.

**Table 1.2**

| substance | standard entropy, $S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$ |
|---|---|
| $CO_2(g)$ | 213.6 |
| $I_2(s)$ | 116.1 |
| $K_2CO_3(s)$ | 155.5 |
| $KI(s)$ | 106.3 |
| $O_2(g)$ | 205.2 |

**(i)** Calculate the standard entropy change, $\Delta S^{\ominus}$, of reaction 1.

$\Delta S^{\ominus}$ = ..... $J\,K^{-1}\,mol^{-1}$ [2]

**(ii)** Use your answer to **(c)(i)** to show that reaction 1 is spontaneous at 298 K.

[2]

**(iii)** The Group 1 carbonates are much more thermally stable than the Group 2 carbonates.

State and explain the trend in the thermal stability of the Group 2 carbonates.

.....

.....

.....

..... [2]

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**(d)** A student electrolyses a solution of KI(aq) for 8 minutes using a direct current.

The half-equation for the reaction that occurs at the anode is given.

$$2I^-(aq) \rightarrow I_2(aq) + 2e^-$$

**(i)** Write a half-equation for the reaction that occurs at the cathode.

Include state symbols.

..... [1]

**(ii)** After the electrolysis, the $I_2(aq)$ produced requires $21.35\,cm^3$ of $0.100\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ to react completely.

$$I_2(aq) + 2Na_2S_2O_3(aq) \rightarrow 2NaI(aq) + Na_2S_4O_6(aq)$$

Calculate the average current used in 8 minutes during the electrolysis.

current = .....A [3]

**(e)** KI is used as a source of $I^-$ ions in organic synthesis.

One example of this is shown in the synthetic route in Fig. 1.1.

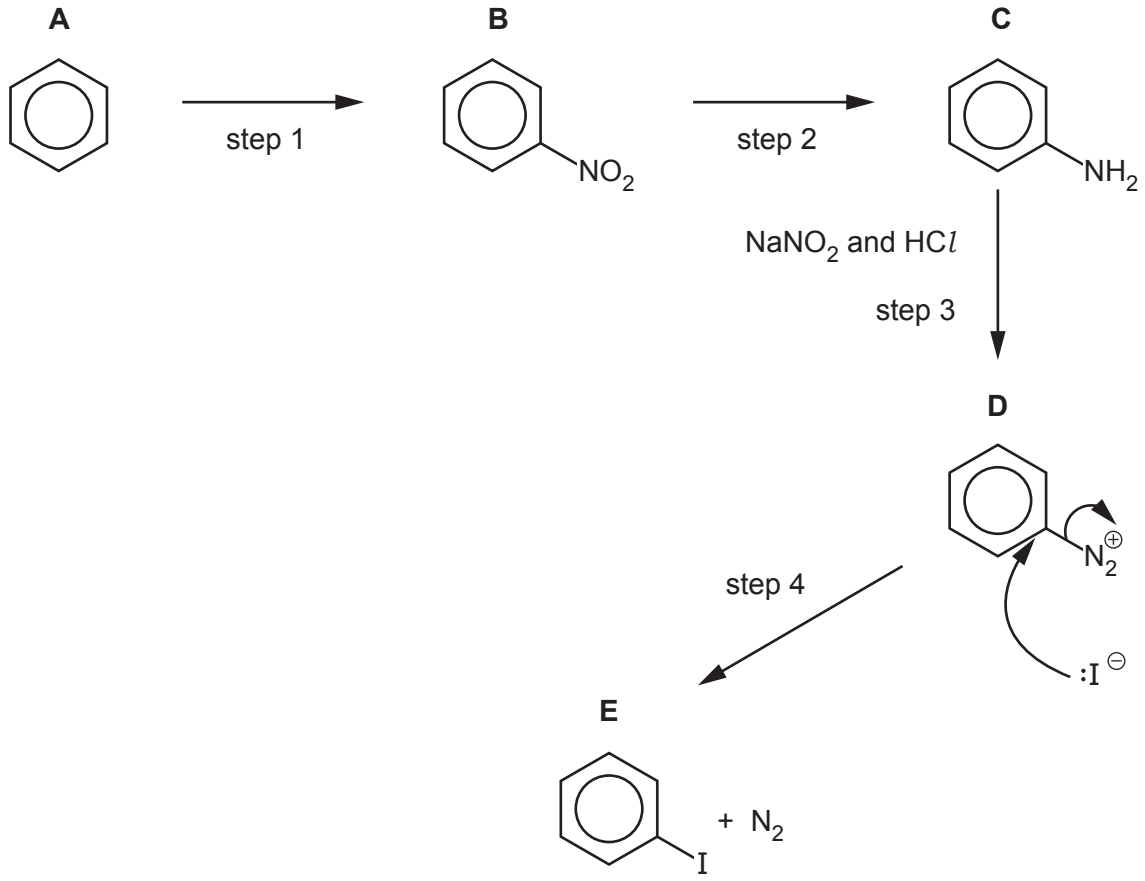



**Fig. 1.1**

**(i)** Identify the reagents required for steps 1 and 2.

step 1 .....

step 2 .....

[2]

**(ii)** Step 3 occurs in two stages.

stage I $NaNO_2$ and $HCl$ undergo an acid–base reaction to produce $HNO_2$.

stage II $HNO_2$ reacts with **C**, $C_6H_5NH_2$, to produce **D**, $C_6H_5N_2^+$.

Complete the equations for stage I and for stage II.

stage I $NaNO_2 + HCl \rightarrow$ .....

stage II .....

[2]

**(iii)** The $I^-$ from KI reacts with **D** in step 4. The mechanism is shown in Fig. 1.1.

Suggest the name for this mechanism.

..... [1]

[Total: 26]

**2** Water is an amphoteric compound that also acts as a good solvent of polar and ionic compounds.

**(a)** Equation 1 shows water acting as a Brønsted–Lowry acid.

equation 1 $H_2O + NO_2^- \rightleftharpoons HNO_2 + OH^-$

**(i)** Identify the **two** conjugate acid–base pairs in equation 1.

| | | | |
|---|---|---|---|
| acid I | $H_2O$ | conjugate base of acid I | |
| acid II | | conjugate base of acid II | |

[1]

**(ii)** Water also behaves as a Brønsted–Lowry acid when it dissolves $CH_3NH_2$.

Explain the ability of $CH_3NH_2$ to act as a base.

..... [1]

**(iii)** Write an equation to show water acting as a base with $CH_3COOH$.

..... [1]

**(b)** The ionic product of water, $K_w$, measures the extent to which water dissociates.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

Fig. 2.1 shows how $K_w$ varies with temperature.

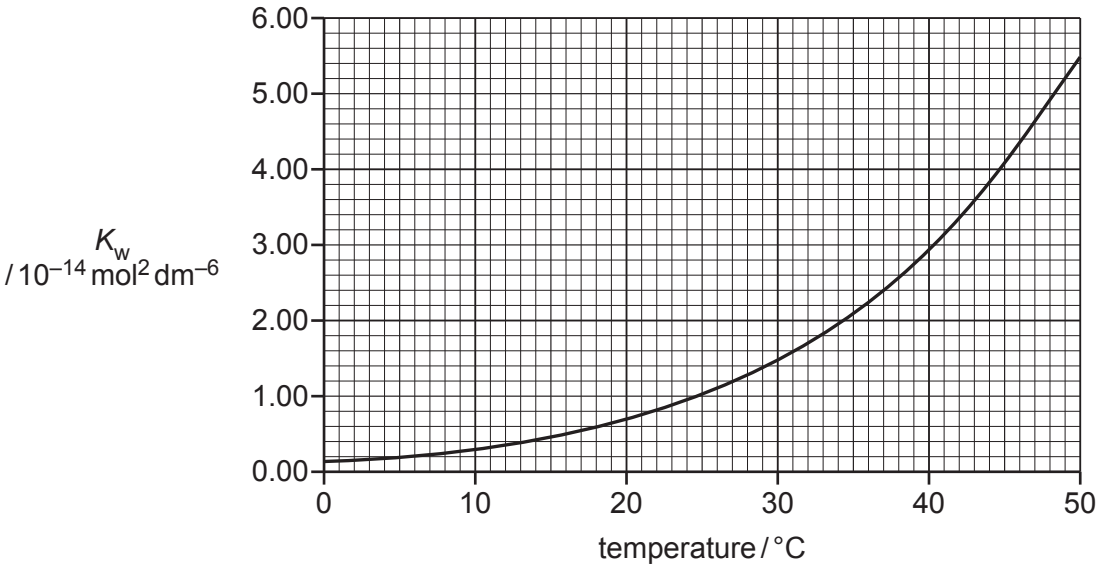



**Fig. 2.1**

**(i)** Write an expression for $K_w$.

..... [1]

**(ii)** Use information from Fig. 2.1 to deduce whether the dissociation of water is an exothermic or an endothermic process.

Explain your answer.

.....

.....

..... [1]

**(iii)** An aqueous solution has pH = 7.00 at 30 °C.

Use information from Fig. 2.1 to explain why this solution can be considered to be alkaline at 30 °C.

.....

.....

.....

..... [2]

**(c)** The three physical states of $H_2O$ have different standard entropies, $S^{\ominus}$, associated with them. Table 2.1 shows these $S^{\ominus}$ values.

**Table 2.1**

| state of $H_2O$ | standard entropy, $S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$ |
|---|---|
| solid | +48.0 |
| liquid | +70.1 |
| gas | +188.7 |

**(i)** Explain the difference in the $S^{\ominus}$ values of $H_2O(s)$ and $H_2O(l)$.

.....

..... [1]

**(ii)** Explain why the increase in $S^{\ominus}$ is **much** greater when $H_2O$ boils than when it melts.

.....

..... [1]

**(iii)** The energy changes for $H_2O(s) \rightarrow H_2O(l)$ are shown.

$\Delta G = 0.00\,kJ\,mol^{-1}$
$\Delta H = +6.03\,kJ\,mol^{-1}$

Use these data to show that the melting point of $H_2O(s)$ is 0 °C.

[1]

**(d)** Metal–air batteries are electrochemical cells that generate electrical energy from the reaction of metal anodes with air.

The standard electrode potentials for the zinc–air battery are shown.

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

$\frac{1}{2}O_2 + H_2O + 2e^- \rightleftharpoons 2OH^-$ $\quad E^\ominus = +0.40\,V$

**(i)** Calculate the standard cell potential, $E^\ominus_{cell}$, of the zinc–air battery.

$E^\ominus_{cell}$ = .....V [1]

**(ii)** The zinc–air battery usually operates at pH 11 and 298 K. The overall cell potential is dependent on $[OH^-]$.

The Nernst equation shows how the electrode potential at the cathode changes with $[OH^-]$.

$$E = 0.40 - \left(\frac{0.059}{z}\right) \log([OH^-]^2)$$

Calculate the electrode potential, $E$, at pH 11.

$E$ = .....V [2]

[Total: 13]

**3** Iron is a transition metal in Group 8 of the Periodic Table.

**(a)** **(i)** Explain why iron has variable oxidation states.

.....

.....

..... [1]

**(ii)** Complete the shorthand electronic configurations of Fe and $Fe^{3+}$.

Fe [Ar].....

$Fe^{3+}$ [Ar].....

[1]

**(b)** An aqueous solution of $Fe(NO_3)_3$ contains the complex $[Fe(H_2O)_6]^{3+}$.

When solutions of KSCN(aq) and $[Fe(H_2O)_6]^{3+}$(aq) are mixed, a colour change is observed. The red complex $[Fe(H_2O)_5SCN]^{2+}$ forms.

**(i)** Define complex.

.....

..... [1]

**(ii)** State the coordination number of Fe in $[Fe(H_2O)_6]^{3+}$.

..... [1]

**(iii)** The H—O—H bond angle in water is 104.5°.

Suggest the H—O—H bond angle in $[Fe(H_2O)_6]^{3+}$.

Explain your answer.

.....

.....

..... [1]

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**(iv)** Explain why iron complexes are coloured.

.....

.....

.....

.....

.....

..... [3]

**(v)** Aqueous solutions of complexes $[Fe(H_2O)_6]^{3+}$ and $[Fe(H_2O)_5SCN]^{2+}$ are different colours.

Explain why these complexes are different colours.

.....

.....

.....

..... [2]

**(c)** Table 3.1 gives values for the stability constants, $K_{stab}$, of different complexes of iron.

**Table 3.1**

| complex | stability constant, $K_{stab}$ |
|---|---|
| $[Fe(H_2O)_5(H_2PO_4)]^{2+}$ | $5.90 \times 10^1$ |
| $[Fe(H_2O)_5SCN]^{2+}$ | $1.30 \times 10^2$ |

**(i)** $[Fe(H_2O)_5(H_2PO_4)]^{2+}$ can form when $H_3PO_4$ reacts with $[Fe(H_2O)_6]^{3+}$.

Write an equation for this reaction.

..... [1]

**(ii)** Write an expression for $K_{stab}$ of $[Fe(H_2O)_5SCN]^{2+}$ and give its units.

$K_{stab}$ =

units = ..... [2]

**(iii)** Use the stability constant data in Table 3.1 to calculate the value of the equilibrium constant, $K_c$, for the following equilibrium.

$$[Fe(H_2O)_5(H_2PO_4)]^{2+} + SCN^- \rightleftharpoons [Fe(H_2O)_5SCN]^{2+} + H_2PO_4^-$$

value of $K_c$ = ..... [1]

[Total: 14]

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**4** Ruthenium and osmium are transition metals below iron in Group 8 of the Periodic Table.

**(a)** Two different complex ions, **X** and **Y**, can form when anhydrous $RuCl_3$ reacts with water under certain conditions.

**X** and **Y** have octahedral geometry.

Aqueous samples of **X** and **Y** react separately with an excess of $AgNO_3(aq)$. Different amounts of $AgCl$ are precipitated:

- 1 mole of complex ion **X** produces 2 moles of $AgCl$
- 1 mole of complex ion **Y** produces 1 mole of $AgCl$.

**(i)** Complete Table 4.1 to suggest formulae for **X** and **Y**.

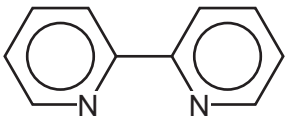
**Table 4.1**

| | **X** | **Y** |
|---|---|---|
| formula of complex | | |

[2]

**(ii)** Both complexes react with an excess of bipyridine, bipy, to form a mixture of two stereoisomers of $[Ru(bipy)_3]^{3+}$.

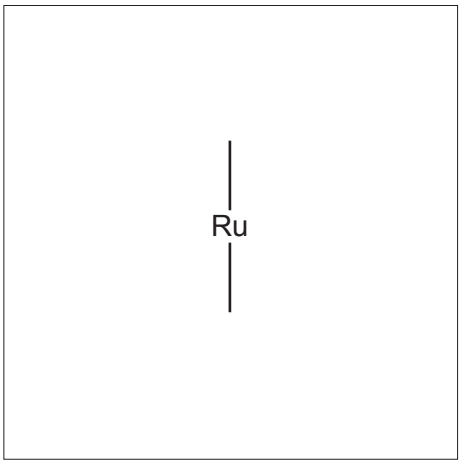
**bipy**

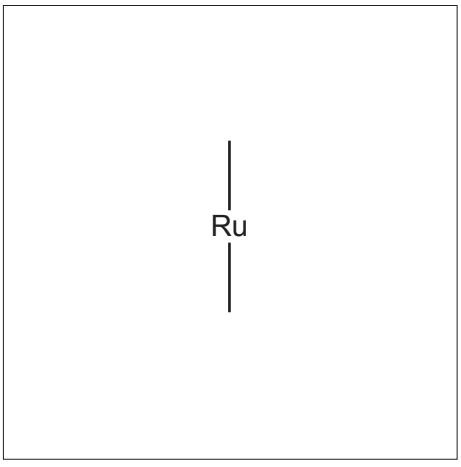



Bipyridine is a bidentate ligand.

Draw three-dimensional diagrams of the two stereoisomers of $[Ru(bipy)_3]^{3+}$.

Use N⌒N to represent the bipy ligand in your structures.




[2]

**(b)** Fig. 4.1 shows another ruthenium complex.

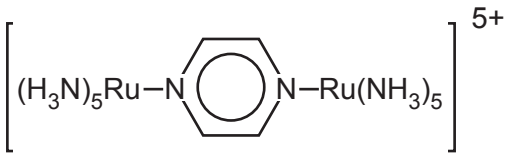
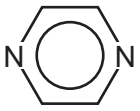



**Fig. 4.1**

This complex contains the neutral ligand pyrazine.

**pyrazine**




**(i)** Suggest how pyrazine is able to bond to two separate ruthenium ions.

.....

.....

..... [1]

**(ii)** Pyrazine is an aromatic compound. The bonding and structure of pyrazine is similar to that of benzene.

Describe and explain the shape of pyrazine.

In your answer, include:

- the hybridisation of the nitrogen and carbon atoms
- how orbital overlap forms $\pi$ bonds between the atoms in the ring.

.....

.....

.....

..... [2]

**(iii)** Predict the number of peaks seen in the carbon–13 NMR spectrum of pyrazine.

Explain your answer.

.....

.....

..... [2]

**(iv)** The overall charge of the ruthenium complex in Fig. 4.1 is 5+.

Deduce the possible oxidation states of the two ruthenium ions in the complex.

..... [1]

**(c)** Osmium tetroxide, $OsO_4$, reacts with alkenes in a similar manner to cold dilute acidified $MnO_4^-$.

Fig. 4.2 shows a proposed synthesis of a condensation polymer **G**.

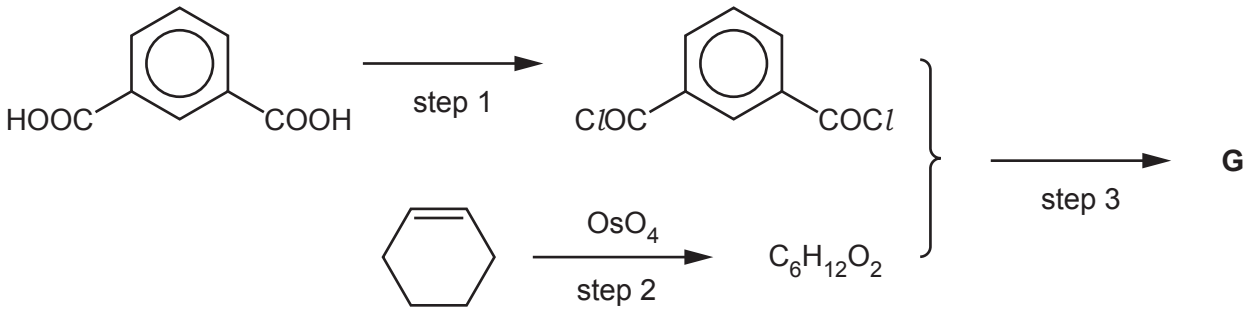



**Fig. 4.2**

**(i)** Suggest a reagent for step 1.

..... [1]

**(ii)** Draw the structure of exactly **one** repeat unit of the condensation polymer **G**.

The ester linkage should be shown fully displayed.

[2]

[Total: 13]

**5** Compound **Q** can be synthesised from chlorobenzene in seven steps, using the route shown in Fig. 5.1.

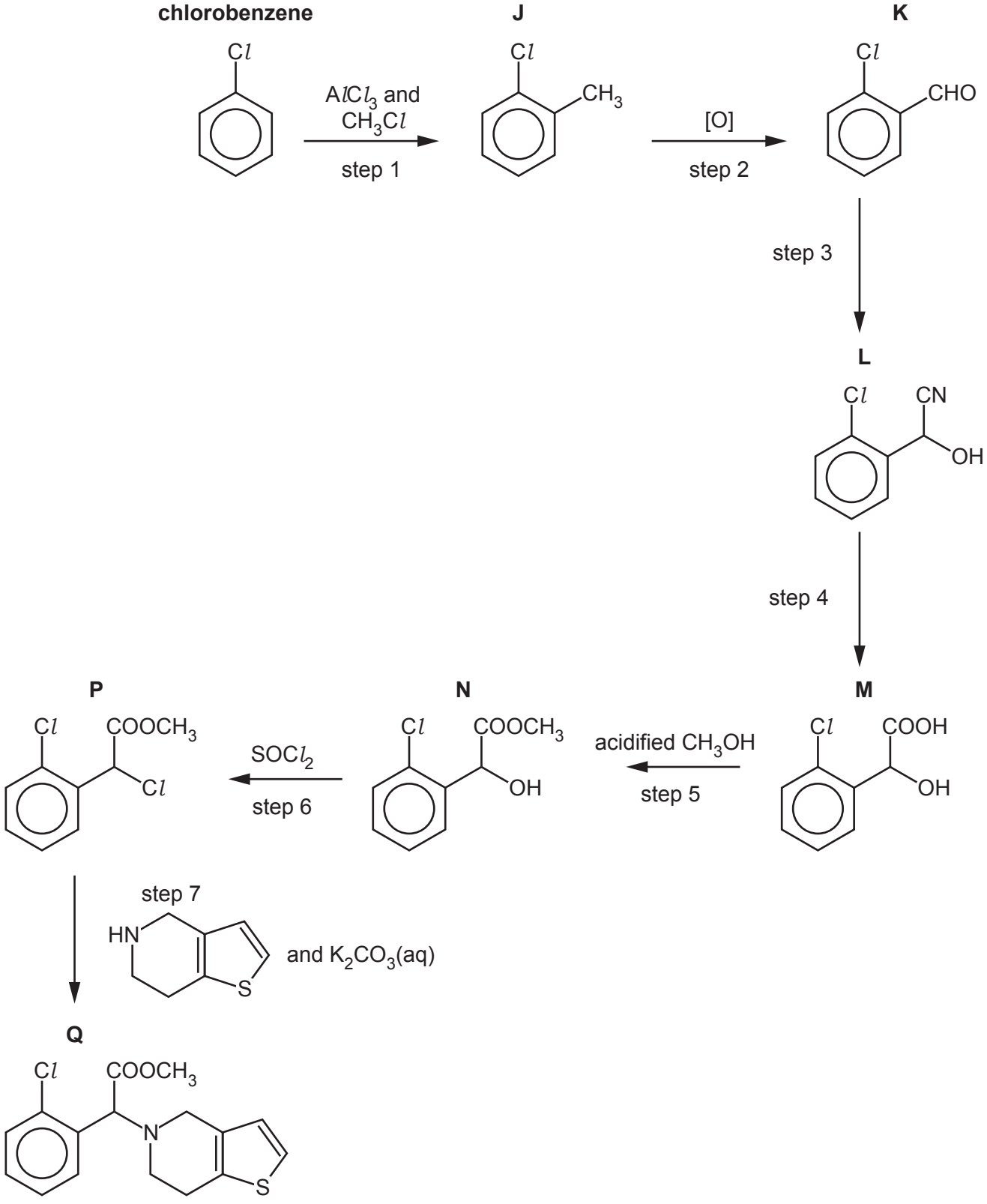



**Fig. 5.1**

**(a) (i)** Write an equation for the formation of the electrophile for step 1.

..... [1]

**(ii)** Complete the mechanism in Fig. 5.2 for step 1, the alkylation of chlorobenzene.

Include all relevant curly arrows and charges.

Draw the structure of the intermediate.

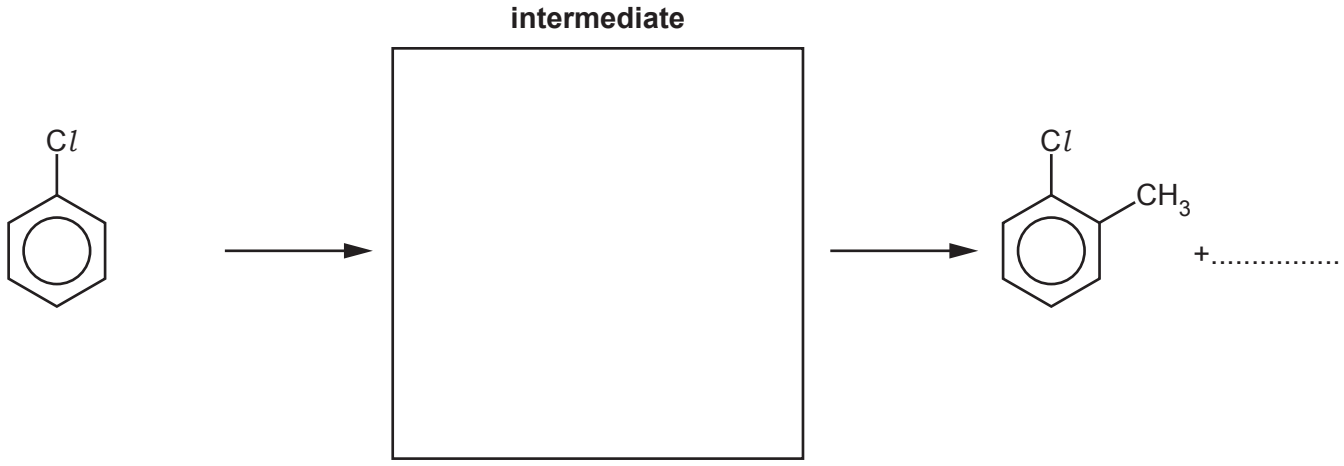



**Fig. 5.2**

[3]

**(iii)** Step 2 is an oxidation reaction.

Construct an equation for the reaction in step 2.

Use [O] to represent an atom of oxygen from an oxidising agent.

..... [1]

**(iv)** Suggest reagents for the conversion of **K** to **M** in steps 3 and 4.

step 3 .....

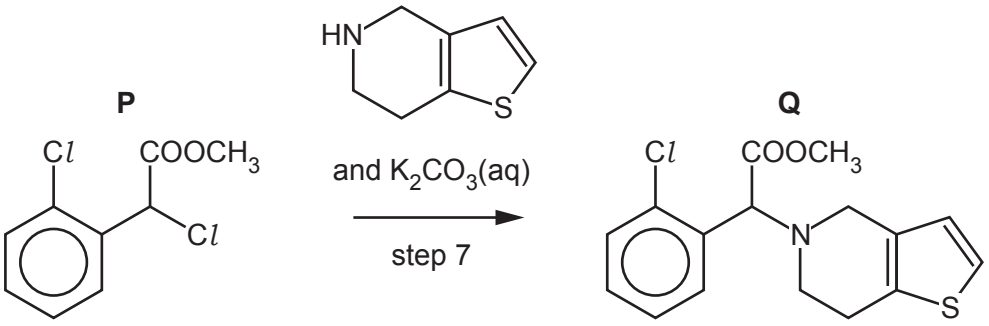
step 4 .....

[2]

**(v)** Identify the type of reaction that occurs in step 5.

..... [1]

**(vi)** Step 7 takes place when **P** is heated with a weak base such as $K_2CO_3$(aq).




Suggest why a strong base such as NaOH(aq) is **not** used for this reaction.

.....

..... [1]

**(vii)** **Q** is optically active.

Explain the meaning of optically active.

.....

.....

..... [1]

**(viii)** Give **two** reasons why it might be desirable to synthesise a single optical isomer of **Q** for use as a drug.

1 .....

.....

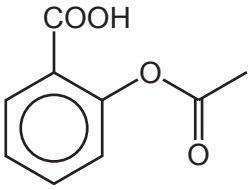
2 .....

.....

[2]

**(b)** **Q** is commonly used in conjunction with aspirin.

**aspirin**




Aspirin is a weak Brønsted–Lowry acid.

**(i)** The p$K_a$ of aspirin is 3.49.

75 mg of aspirin dissolves in water to form 100 $cm^3$ of an aqueous solution.

Calculate the pH of this solution.

[$M_r$: aspirin, 180.0]

pH = ..... [3]

**(ii)** Aspirin undergoes acid hydrolysis in the stomach.

Give the structures of the organic products of this acid hydrolysis.

[2]

[Total: 17]

**6** Amino acids are molecules that contain —$NH_2$ and —COOH functional groups.

Glycine, $H_2NCH_2COOH$, is the simplest stable amino acid.

**(a)** The isoelectric point of glycine is 6.2.

**(i)** Define isoelectric point.

.....

..... [1]

**(ii)** Draw the structure of glycine at pH 4.

[1]

**(b)** Fig. 6.1 shows two syntheses starting with glycine.

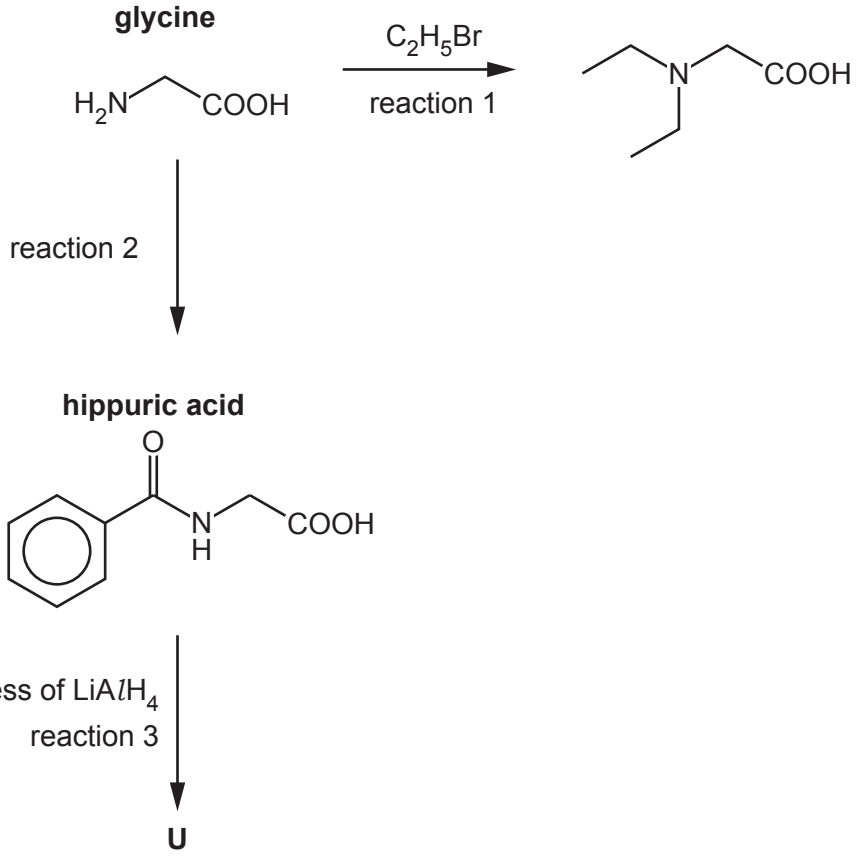



**Fig. 6.1**

**(i)** State the essential conditions for reaction 1.

..... [1]

**(ii)** Identify the reagent used in reaction 2.

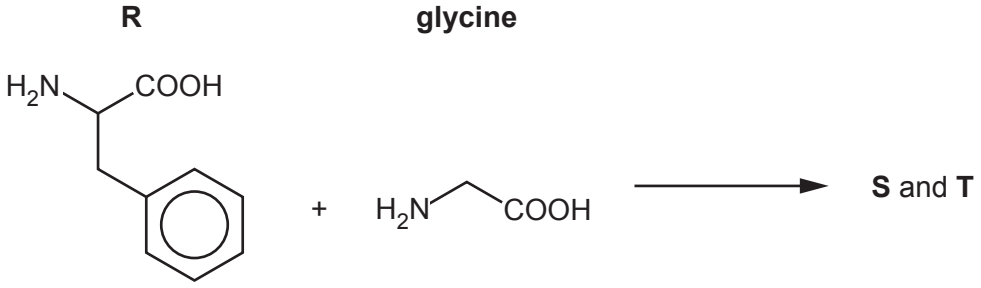
..... [1]

**(iii)** Draw the structure of the organic product **U** that forms when hippuric acid reacts with an excess of $LiAlH_4$ in reaction 3.

[2]

**(iv)** A molecule of phenylalanine, **R**, can react with a molecule of glycine to form two dipeptides, **S** and **T**.

**S** and **T** are structural isomers.




Draw the structures of these dipeptides. The peptide bond formed should be shown fully displayed.

| **S** | **T** |
| --- | --- |
| | |

[2]

**(c)** A student proposes a synthesis of hippuric acid by the reaction of benzamide, $C_6H_5CONH_2$, and chloroethanoic acid, $Cl CH_2COOH$.

The reaction does **not** work well because benzamide is a very weak base.

**(i)** Explain why amides are weaker bases than amines.

.....

.....

.....

..... [2]

**(ii)** The p$K_a$ of chloroethanoic acid is 2.86 whereas the p$K_a$ of ethanoic acid is 4.76.

Explain the difference between these two p$K_a$ values.

.....

.....

.....

..... [2]

**(d)** Compound **V** is another amino acid.

The proton ($^1$H) NMR spectrum of **V** shows hydrogen atoms in five different environments, **a**, **b**, **c**, **d** and **e**, as shown in Fig. 6.2.

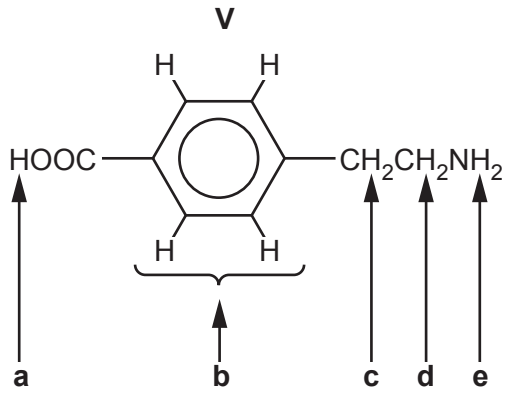



**Fig. 6.2**

**Table 6.1**

| environment of proton | example | chemical shift range, δ / ppm |
|---|---|---|
| alkane | –C**H**$_3$, –C**H**$_2$–, >C**H**– | 0.9–1.7 |
| alkyl next to C=O | C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O | 2.2–3.0 |
| alkyl next to aromatic ring | C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar | 2.3–3.0 |
| alkyl next to electronegative atom | C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–C*l*, –C**H**$_2$–N | 3.2–4.0 |
| attached to alkene | =C**H**R | 4.5–6.0 |
| attached to aromatic ring | **H**–Ar | 6.0–9.0 |
| aldehyde | **H**COR | 9.3–10.5 |
| alcohol | RO**H** | 0.5–6.0 |
| phenol | Ar–O**H** | 4.5–7.0 |
| carboxylic acid | RCOO**H** | 9.0–13.0 |
| alkyl amine | R–N**H**– | 1.0–5.0 |
| aryl amine | Ar–N**H**$_2$ | 3.0–6.0 |
| amide | RCON**H**R | 5.0–12.0 |

**(i)** Complete Table 6.2 for the proton ($^1$H) NMR spectrum of **V** taken in CDC*l*$_3$.

Table 6.1 gives some relevant data.

**Table 6.2**

| proton | **a** | **b** | **c** | **d** | **e** |
|---|---|---|---|---|---|
| chemical shift range, δ / ppm | | | | | |
| name of splitting pattern | | multiplet | | | |

[4]

**(ii)** Complete Table 6.3 by placing a tick (✓) to indicate any protons whose peaks are still present in the proton ($^1$H) NMR spectrum of **V** taken in $D_2O$.

**Table 6.3**

| proton | **a** | **b** | **c** | **d** | **e** |
|---|---|---|---|---|---|
| present in $D_2O$ | | | | | |

[1]

[Total: 17]

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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)<br>$V_m = 24.0\,\text{dm}^3\,\text{mol}^{-1}$ 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 | $c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$) |

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## The Periodic Table of Elements

| Group | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | | | | | | | | | | | 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 – |

**Key**

atomic number
**atomic symbol**
name
relative atomic mass

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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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