Cambridge International AS & A Level

CANDIDATE NAME									
CENTRE NUMBER						CANDIDATE NUMBER			

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CHEMISTRY **9701/23**

Paper 2 AS Level Structured Questions **May/June 2024**

1 hour 15 minutes

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 60.
- 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 **16** pages.

DC (CJ/SW) 324894/3

1 (a) (i) Explain the lack of reactivity of nitrogen gas, $N_2(g)$.

....

....

.... [2]

(ii) Covalent bonds can be σ bonds or π bonds.

Complete Table 1.1 to show the number of σ and π bonds in a molecule of N_2 and to describe how the orbitals overlap to form σ and π bonds.

Table 1.1

	σ bond	π bond
number of bonds in N_2		
how the orbitals overlap		

[4]

(b) (i) A sample of A*l* reacts with an excess of Cl_2.

State the oxidation number of A*l* in the product of the reaction.

oxidation number of A*l* .... [1]

(ii) State what determines the maximum oxidation number of the Period 3 elements in their oxides.

....

.... [1]

(c) Separate samples of aluminium oxide, Al_2O_3, and phosphorus(V) oxide, P_4O_{10}, react with an excess of NaOH(aq) at room temperature.

(i) Give the state of Al_2O_3 and P_4O_{10} at room temperature.

Al_2O_3 ....

P_4O_{10} .... [1]

(ii) Write an equation for the reaction of each oxide with an excess of NaOH(aq) at room temperature.

Al_2O_3 + ...

P_4O_{10} + ... [2]

(d) The oxide of silicon reacts with calcium oxide in an addition reaction to produce calcium silicate, $CaSiO_3$. The oxidation number of calcium in $CaSiO_3$ is +II.

(i) Deduce the oxidation number of silicon in calcium silicate.

oxidation number of silicon .... [1]

(ii) Calcium oxide can be made from calcium carbonate in a single-step reaction.

Identify the type of reaction that occurs.

.... [1]

[Total: 13]

2 N_2(g) reacts with H_2(g) in the Haber process, as shown in reaction 1.

reaction 1 $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -x\ kJ\,mol^{-1}$

Table 2.1 shows the different conditions used to produce three equilibrium mixtures, **A**, **B** and **C**.

Table 2.1

	A	**B**	**C**
initial molar ratio of $N_2 : H_2$ added	1 : 3	1 : 3	1 : 3
temperature / °C	500	500	1000
pressure / atm	1000	1000	1000
iron present in mixture	no	yes	no
percentage yield of NH_3(g) at equilibrium	58	x	y

(a) Describe and explain the change, if any, to the percentage yield of NH_3(g) produced in **B** compared to **A**.

....

....

.... [1]

(b) **(i)** Describe and explain the change, if any, to the percentage yield of NH_3(g) produced in **C** compared to **A**.

....

....

.... [1]

(ii) Describe and explain the change to the rate of the forward reaction that occurs to establish the equilibrium in **C** compared to **A**.

You do **not** need to refer to the Boltzmann distribution in your answer.

....

....

....

.... [2]

(c) **(i)** Write an expression for the equilibrium constant, K_p, for reaction 1. State the units.

K_p =

units ....
[2]

(ii) Equilibrium mixture **D** is made when 1.0 mol of N_2(g) and 3.0 mol of H_2(g) are added to a sealed container at 750 °C and 1000 atm and left to reach equilibrium. This mixture contains 1.16 mol of NH_3(g).

Calculate the mole fraction of NH_3(g) in **D**.

mole fraction of NH_3(g) = ... [2]

(iii) The mole fraction of N_2(g) is 0.625 in a new equilibrium mixture, **E**.

Calculate the partial pressure of N_2(g) in **E** when the total pressure is 1000 atm.

partial pressure of N_2(g) = ... atm [1]

(d) When oxides of nitrogen escape into the atmosphere they may be involved in:

- formation of acid rain from sulfur dioxide
- formation of photochemical smog.

(i) Identify the role of NO and NO_2 in the formation of H_2SO_4 from SO_2 in the atmosphere to produce acid rain.

Use relevant equations to support your answer.

....

....

....

....

....

.... [3]

(ii) Outline how NO and NO_2 may contribute to the formation of photochemical smog.

....

....

.... [2]

[Total: 14]

3 **(a)** Write an equation to show the reaction for the standard enthalpy change of formation of H_2O. Include state symbols.

.... [2]

(b) Water is one of the products in the reaction of B_2O_3 and NH_3, as shown in reaction 2.

reaction 2 $B_2O_3 + 2NH_3 \rightarrow 2BN + 3H_2O$

Table 3.1 shows information about the standard enthalpy change of formation, $\Delta H_f^\ominus$, of some substances.

Table 3.1

substance	$\Delta H_f^\ominus$ / kJ mol^{-1}
B_2O_3	–1264
NH_3	–46
BN	–134
H_2O	–286

Calculate the enthalpy change, ΔH, for reaction 2 using the data from Table 3.1.

ΔH = ... kJ mol^{-1} [2]

(c) Boron carbide is a hard crystalline solid that has a melting point greater than 2000 °C.

(i) Suggest the structure and bonding in boron carbide.

.... [1]

(ii) 100 g of pure boron carbide contains 78.26 g of boron.

Calculate the empirical formula of boron carbide.

Show your working.

empirical formula of boron carbide .... [2]

[Total: 7]

4 **(a)** $NH_3(g)$ reacts with $HCl(g)$ to produce $NH_4Cl(s)$, as shown.

$$NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$$

Draw a diagram to show the ionic, covalent and coordinate bonding present in a formula unit of NH_4Cl.

[2]

(b) An exothermic reaction occurs when $NH_4^+(aq)$ is added to $OH^-(aq)$.

(i) Identify the type of reaction.

.... [1]

(ii) Construct an ionic equation for the reaction of NH_4^+ and OH^-.

.... [1]

(c) Substitution reactions of NH_3 and OH^- with halogenoalkanes both involve a lone pair of electrons.

(i) Name the role of NH_3 and OH^- in these reactions.

.... [1]

(ii) Suggest which species, NH_3 or OH^-, is more reactive during these reactions. Explain your answer.

....

....

.... [1]

(d) When 2-bromo-2-methylpropane reacts with OH^-, two mechanisms, S_N1 and S_N2, both occur. The S_N2 mechanism has a slower rate.

Fig. 4.1 shows the reaction pathway diagram for the S_N1 mechanism.

Sketch a graph on Fig. 4.1 to show the reaction pathway for the S_N2 mechanism.

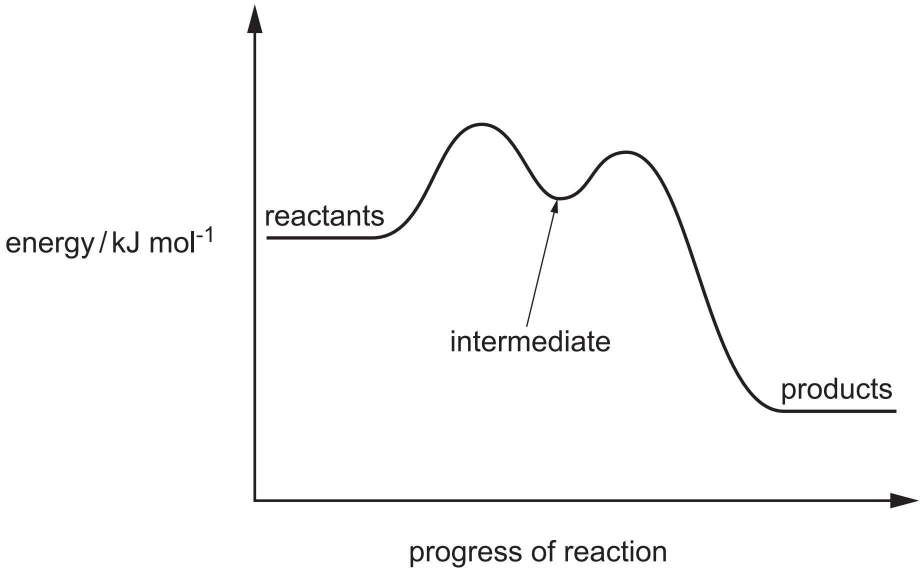


Fig. 4.1

[2]

(e) **(i)** Complete Fig. 4.2 to show the mechanism for the S_N1 reaction that occurs when $CH_3CHBrC_2H_5$ reacts with NH_3 to produce $CH_3CH(NH_2)C_2H_5$.
Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

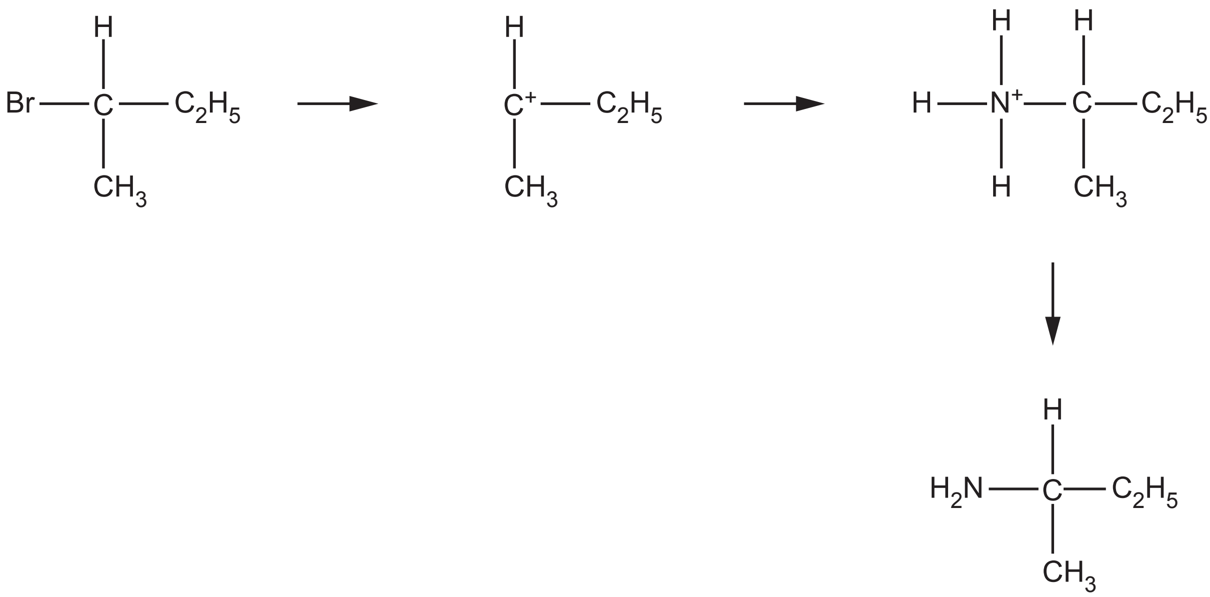


Fig. 4.2

[3]

(ii) Identify the inorganic product that forms in the reaction in Fig. 4.2.

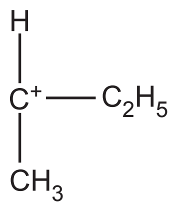
.... [1]

(iii) Give the systematic name for the organic product $CH_3CH(NH_2)C_2H_5$.

.... [1]

(f) **(i)** Complete Table 4.1 by drawing the structural formula of the intermediate that is formed when 2-bromo-2-methylpropane reacts in an S_N1 reaction.

Table 4.1

	2-bromobutane	2-bromo-2-methylpropane
structural formula of intermediate in S_N1 reaction		

[1]

(ii) Identify the halogenoalkane in Table 4.1 that has the greater tendency to react using the S_N1 mechanism. Explain your answer.

....

....

.... [2]

[Total: 16]

5 **(a)** **M** reacts to form **R** by the addition of one reagent, as shown in Fig. 5.1.

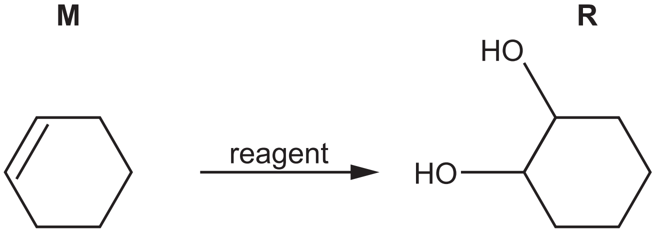


Fig. 5.1

Identify the reagent and conditions for this reaction.

.... [1]

(b) **R** is also made from **M** by two steps, as shown in Fig. 5.2.

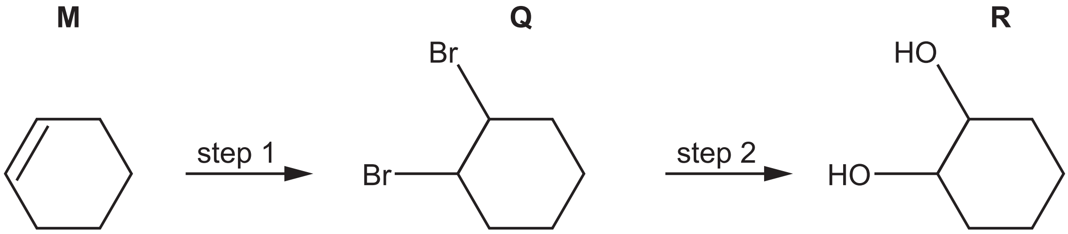


Fig. 5.2

(i) Identify the reagents and conditions for steps 1 and 2 in Fig. 5.2.

step 1 ....

step 2 ....
[2]

(ii) Name the mechanism for step 1 in Fig. 5.2.

.... [1]

(c) The infrared spectrum of **R** is shown in Fig. 5.3.

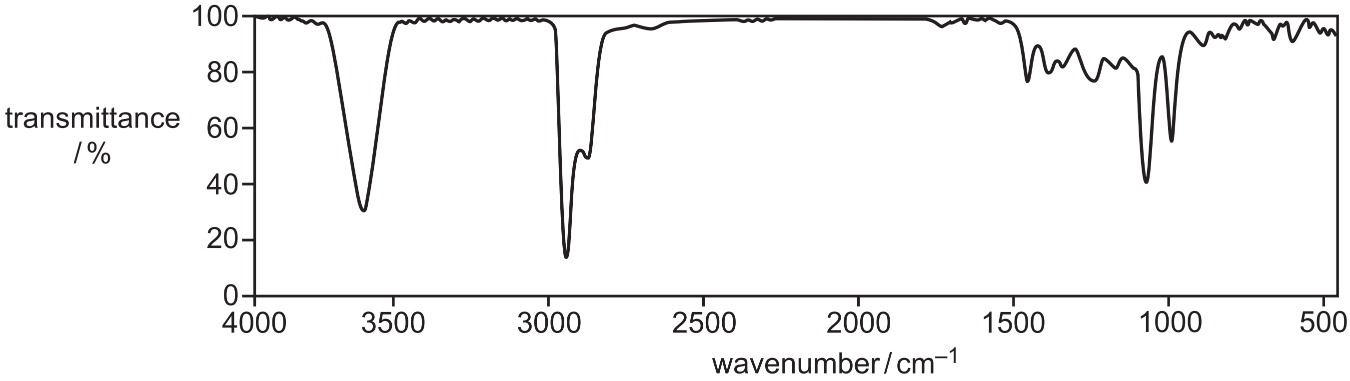


Fig. 5.3

Table 5.1

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

Use the absorptions in the region above 1500 cm^{-1} in Table 5.1 when answering this question.

- Add **F** to Fig. 5.3 to identify the peak that is present in an infrared spectrum of both **Q** and **R**. Identify the bond that corresponds to the absorption for **F**.

  ....

- Add **G** to Fig. 5.3 to identify the peak that is **not** present in an infrared spectrum of **Q**. Identify the bond that corresponds to the absorption for **G**.

  ....

[2]

(d) **Y** is made from **Q** in a three-step reaction.

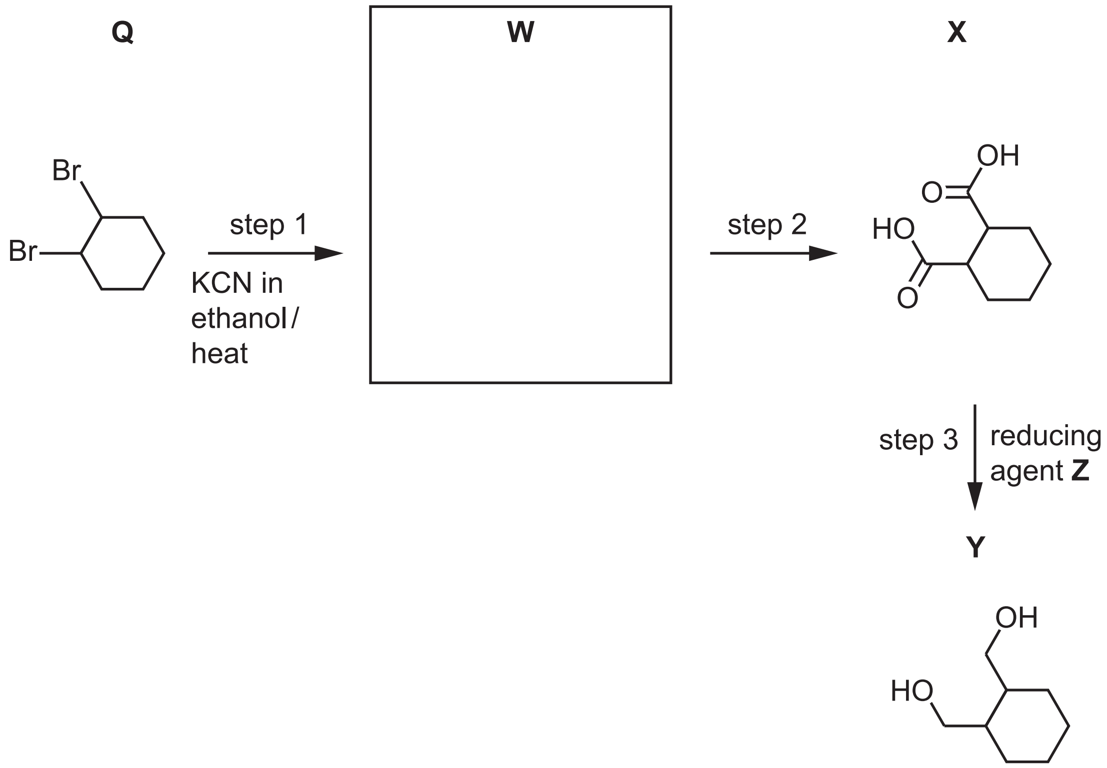


Fig. 5.4

(i) Draw the structure of **W** in the box in Fig. 5.4. [1]

(ii) In step 2, **W** is heated with HCl(aq) to produce **X** and an inorganic product.

Identify the formula of the inorganic product.

.... [1]

(iii) In step 3, **X** reacts with reducing agent **Z** to produce **Y**.

Complete the equation for the reaction of **X** with **Z**.

Use a molecular formula to represent the organic product.

Use [H] to represent one atom of hydrogen from **Z**.

…… $C_8H_{12}O_4$ + ……[H] $\rightarrow$ .... [1]

(iv) Identify **Z**.

.... [1]

[Total: 10]

Important values, constants and standards

molar gas constant	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,C\,mol^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23}\,mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,C$
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	$K_w = 1.00 \times 10^{-14}\,mol^{2}\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,kJ\,kg^{-1}\,K^{-1}$ ($4.18\,J\,g^{-1}\,K^{-1}$)

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 –