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9701/23

May/June 2024

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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.

2

- 1 (a) (i) Explain the lack of reactivity of nitrogen gas, $\text{N}_2(\text{g})$.

.....

.....

..... [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 Al reacts with an excess of Cl_2 .

State the oxidation number of Al in the product of the reaction.

oxidation number of Al [1]

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

.....

..... [1]

3

- (c) Separate samples of aluminium oxide, Al_2O_3 , and phosphorus(V) oxide, P_4O_{10} , react with an excess of $\text{NaOH}(\text{aq})$ 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 $\text{NaOH}(\text{aq})$ 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]

4

- 2 $\text{N}_2(\text{g})$ reacts with $\text{H}_2(\text{g})$ in the Haber process, as shown in reaction 1.

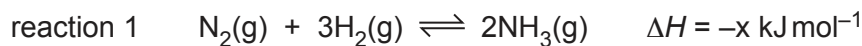


Table 2.1 shows the different conditions used to produce three equilibrium mixtures, **A**, **B** and **C**.

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 $\text{NH}_3(\text{g})$ at equilibrium	58	x	y

- (a) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **B** compared to **A**.

.....

 [1]

- (b) (i) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ 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]

5

- (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 $\text{N}_2(\text{g})$ and 3.0 mol of $\text{H}_2(\text{g})$ are added to a sealed container at 750°C and 1000 atm and left to reach equilibrium. This mixture contains 1.16 mol of $\text{NH}_3(\text{g})$.

Calculate the mole fraction of $\text{NH}_3(\text{g})$ in **D**.

mole fraction of $\text{NH}_3(\text{g}) =$ [2]

- (iii) The mole fraction of $\text{N}_2(\text{g})$ is 0.625 in a new equilibrium mixture, **E**.

Calculate the partial pressure of $\text{N}_2(\text{g})$ in **E** when the total pressure is 1000 atm.

partial pressure of $\text{N}_2(\text{g}) =$ atm [1]

6

(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 NO₂ in the formation of H₂SO₄ from SO₂ in the atmosphere to produce acid rain.

Use relevant equations to support your answer.

.....

.....

.....

.....

.....

..... [3]

(ii) Outline how NO and NO₂ may contribute to the formation of photochemical smog.

.....

.....

..... [2]

[Total: 14]

7

- 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.

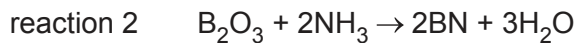


Table 3.1 shows information about the standard enthalpy change of formation, $\Delta H_f^\ominus$, of some substances.

Table 3.1

substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
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.

$\Delta H = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

8

(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.

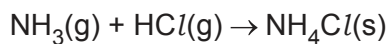
Show your working.

empirical formula of boron carbide [2]

[Total: 7]

9

- 4 (a) $\text{NH}_3(\text{g})$ reacts with $\text{HCl}(\text{g})$ to produce $\text{NH}_4\text{Cl}(\text{s})$, as shown.



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 $\text{NH}_4^+(\text{aq})$ is added to $\text{OH}^-(\text{aq})$.

- (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]

10

- (d) When 2-bromo-2-methylpropane reacts with OH^- , two mechanisms, $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$, both occur. The $\text{S}_{\text{N}}2$ mechanism has a slower rate.

Fig. 4.1 shows the reaction pathway diagram for the $\text{S}_{\text{N}}1$ mechanism.

Sketch a graph on Fig. 4.1 to show the reaction pathway for the $\text{S}_{\text{N}}2$ mechanism.

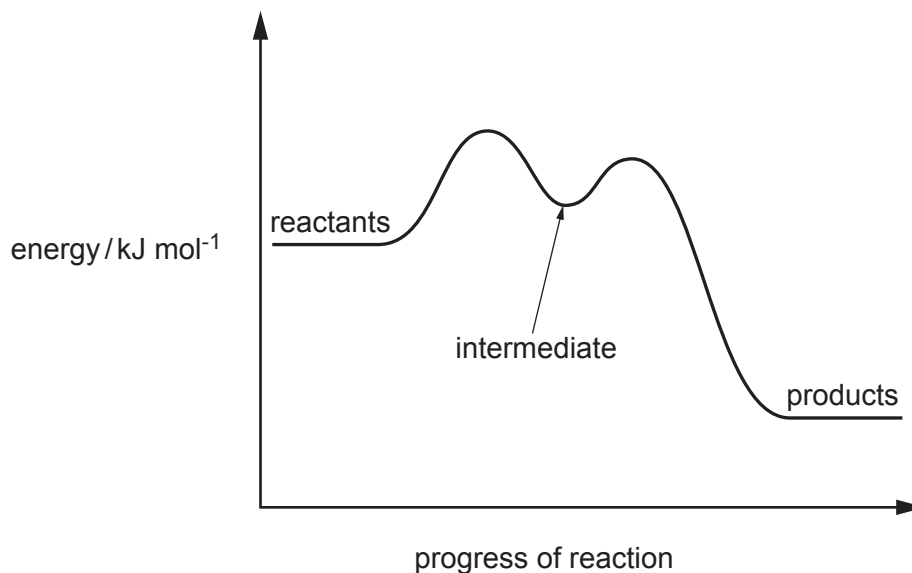


Fig. 4.1

[2]

- (e) (i) Complete Fig. 4.2 to show the mechanism for the $\text{S}_{\text{N}}1$ reaction that occurs when $\text{CH}_3\text{CHBrC}_2\text{H}_5$ reacts with NH_3 to produce $\text{CH}_3\text{CH}(\text{NH}_2)\text{C}_2\text{H}_5$. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

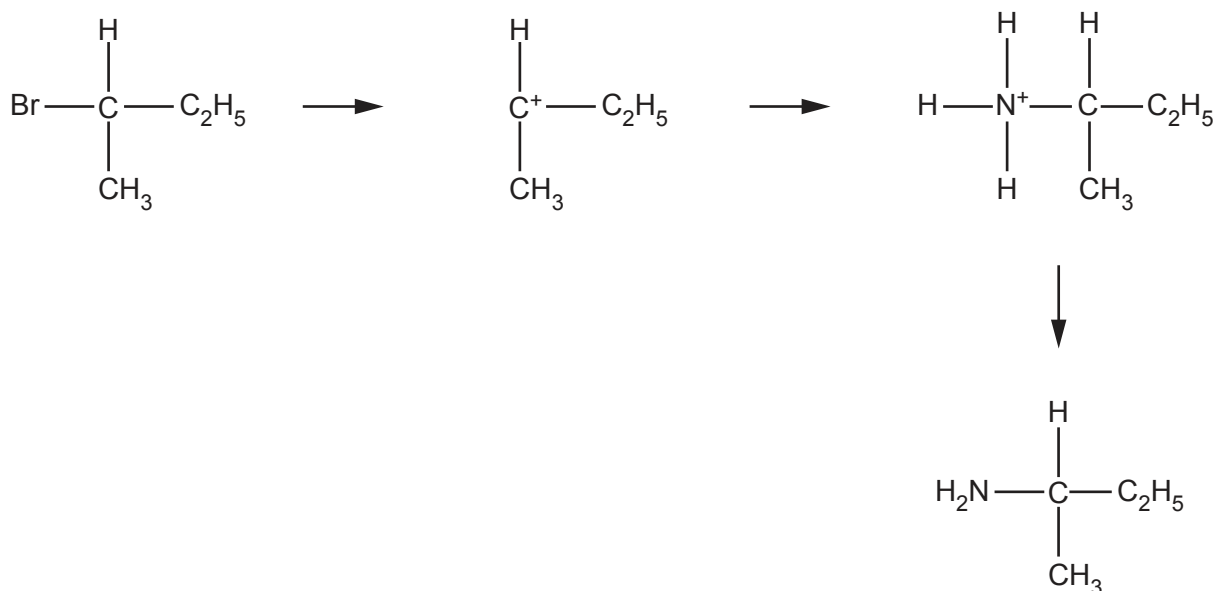


Fig. 4.2

[3]

11

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

..... [1]

(iii) Give the systematic name for the organic product $\text{CH}_3\text{CH}(\text{NH}_2)\text{C}_2\text{H}_5$.

..... [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 $\text{S}_{\text{N}}1$ reaction.

Table 4.1

	2-bromobutane	2-bromo-2-methylpropane
structural formula of intermediate in $\text{S}_{\text{N}}1$ reaction	$\begin{array}{c} \text{H} \\ \\ \text{C}^+ - \text{C}_2\text{H}_5 \\ \\ \text{CH}_3 \end{array}$	

[1]

(ii) Identify the halogenoalkane in Table 4.1 that has the greater tendency to react using the $\text{S}_{\text{N}}1$ mechanism. Explain your answer.

.....

 [2]

[Total: 16]

12

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

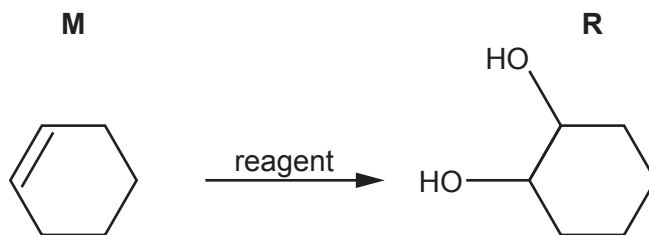


Fig. 5.1

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.

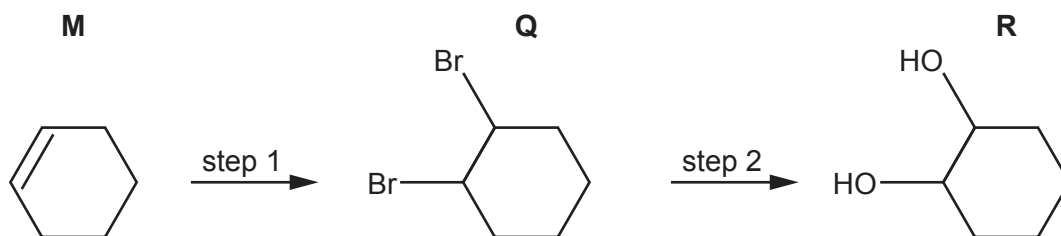


Fig. 5.2

- (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]

13

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

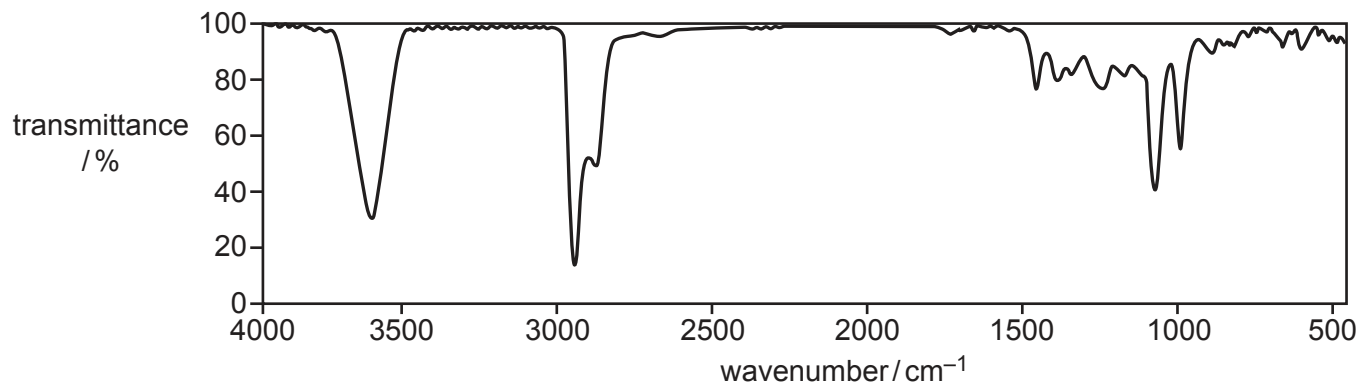


Fig. 5.3

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]

14

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

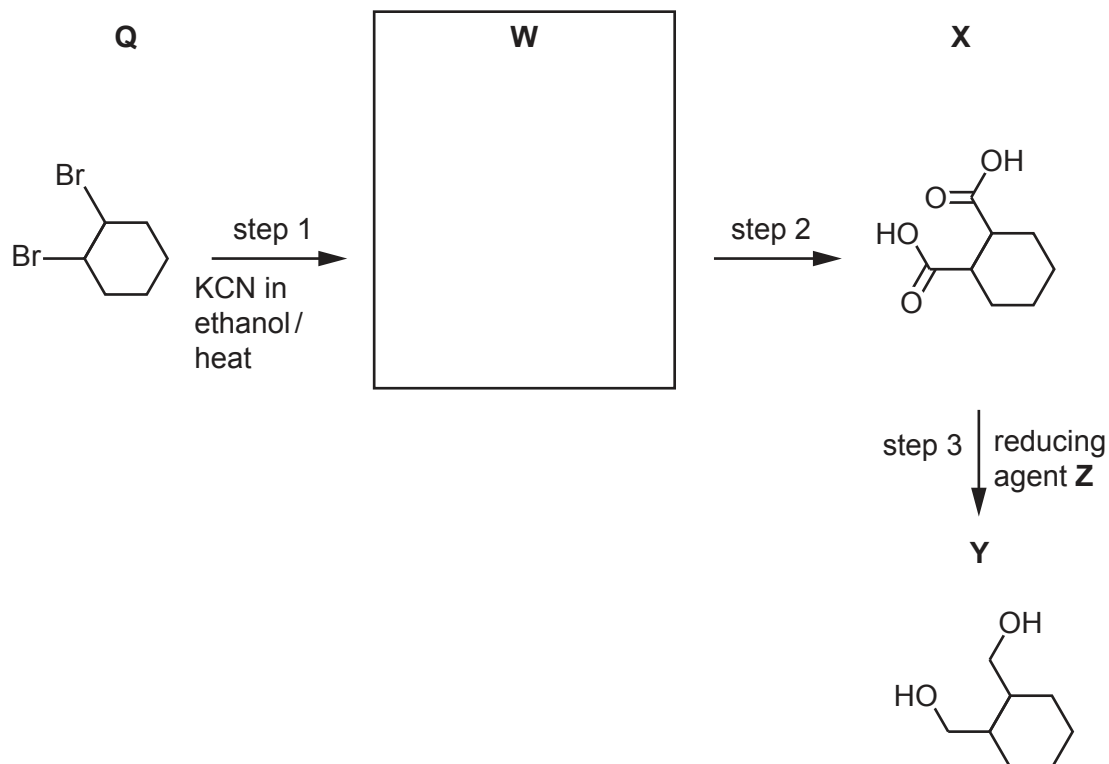


Fig. 5.4

- (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 $[\text{H}]$ to represent one atom of hydrogen from **Z**.
..... $\text{C}_8\text{H}_{12}\text{O}_4 + \dots[\text{H}] \rightarrow \dots$ [1]
- (iv) Identify **Z**.
..... [1]
- [Total: 10]

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)

Group																																				
1	2	Key							1						13	14	15	16	17	18																
		atomic number atomic symbol name relative atomic mass										H hydrogen 1.0																								
3	Li lithium 6.9	4	Be beryllium 9.0																																	
11	Na sodium 23.0	12	Mg magnesium 24.3	3	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	12	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	He helium 4.0
19	K potassium 39.1	20	Ca calcium 40.1	39	Y yttrium 88.9	38	Sr strontium 87.6	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	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 —	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 —	Og oganesson —		

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	euroium	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
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	208.9
84	Po	polonium	—
85	At	astatine	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	—
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	—

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	euroium	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
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	208.9
84	Po	polonium	—
85	At	astatine	—
86	Rn	radon	—
87	Fr	francium	—
88	Ra	radium	—
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	—