Cambridge International AS & A Level

CANDIDATE NAME	

CENTRE NUMBER						CANDIDATE NUMBER					

CHEMISTRY **9701/52**

Paper 5 Planning, Analysis and Evaluation **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 30.
- 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 **12** pages.

DC (PQ/CT) 326110/3

[Turn over

1 Calcium carbonate, $CaCO_3(s)$, decomposes when heated, as shown.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

The enthalpy change of reaction, ΔH_r, for the thermal decomposition of $CaCO_3(s)$ **cannot** be measured directly. Instead, a procedure involving two experiments is used. In each experiment, the enthalpy change of a different reaction is determined.

The equation for the reaction in experiment 1 is shown. The enthalpy change for this reaction is ΔH_1.

experiment 1 $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

The equation for the reaction in experiment 2 is shown. The enthalpy change for this reaction is ΔH_2.

experiment 2 $CaO(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l)$

Experiment 1

step 1 Weigh a 0.0500 mol sample of powdered $CaCO_3(s)$.

step 2 Transfer 50.00 cm^3, an excess, of 2.00 mol dm^{-3} hydrochloric acid, $HCl(aq)$, into a small glass beaker.

step 3 Start a timer and measure the temperature of the $HCl(aq)$ in the beaker every 30 seconds for $2\frac{1}{2}$ minutes.

step 4 After 3 minutes add the sample of $CaCO_3(s)$ to the $HCl(aq)$ in the beaker. Continue measuring the temperature of the reaction mixture every 30 seconds for a further 5 minutes.

Experiment 2

Repeat experiment 1 using calcium oxide, $CaO(s)$, instead of $CaCO_3(s)$.

(a) Suggest why the enthalpy change of reaction for the thermal decomposition of calcium carbonate **cannot** be measured directly.

.... [1]

(b) **(i)** Calculate the mass, in g, of $CaCO_3(s)$ to be weighed using a two-decimal-place balance in step 1.

mass of $CaCO_3(s)$ = ... g [1]

(ii) Outline how a student should weigh by difference using a weighing boat in order to determine the exact mass of $CaCO_3$(s) added to HCl(aq) in the beaker. Draw a results table, with appropriate headings, ready for the student to complete.

....

....

[2]

(c) Identify which piece of apparatus should be used to measure the volume of HCl(aq) in step 2 and give a reason for your choice.

....

.... [1]

(d) Without making any changes to the apparatus, suggest an instruction to be added to step 3 and step 4 to make the experiment more accurate.

.... [1]

(e) A student carries out experiment 1 and obtains the results given in Table 1.1.

Table 1.1

time / minutes	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
temperature / °C	19.0	19.0	19.0	19.0	19.0	☒	27.5	36.0	34.5	32.5	32.0	31.0

time / minutes	6.5	7.0	7.5	8.0
temperature / °C	29.0	28.0	26.0	25.5

(i) Plot a graph on the grid in Fig. 1.1 to show the relationship between temperature and time. Use a cross (×) to plot each data point.

The points and line of best fit for the data before 3 minutes have been drawn for you. Draw a line of best fit for the data after 3 minutes that will enable you to determine the theoretical temperature increase at 3.0 minutes.

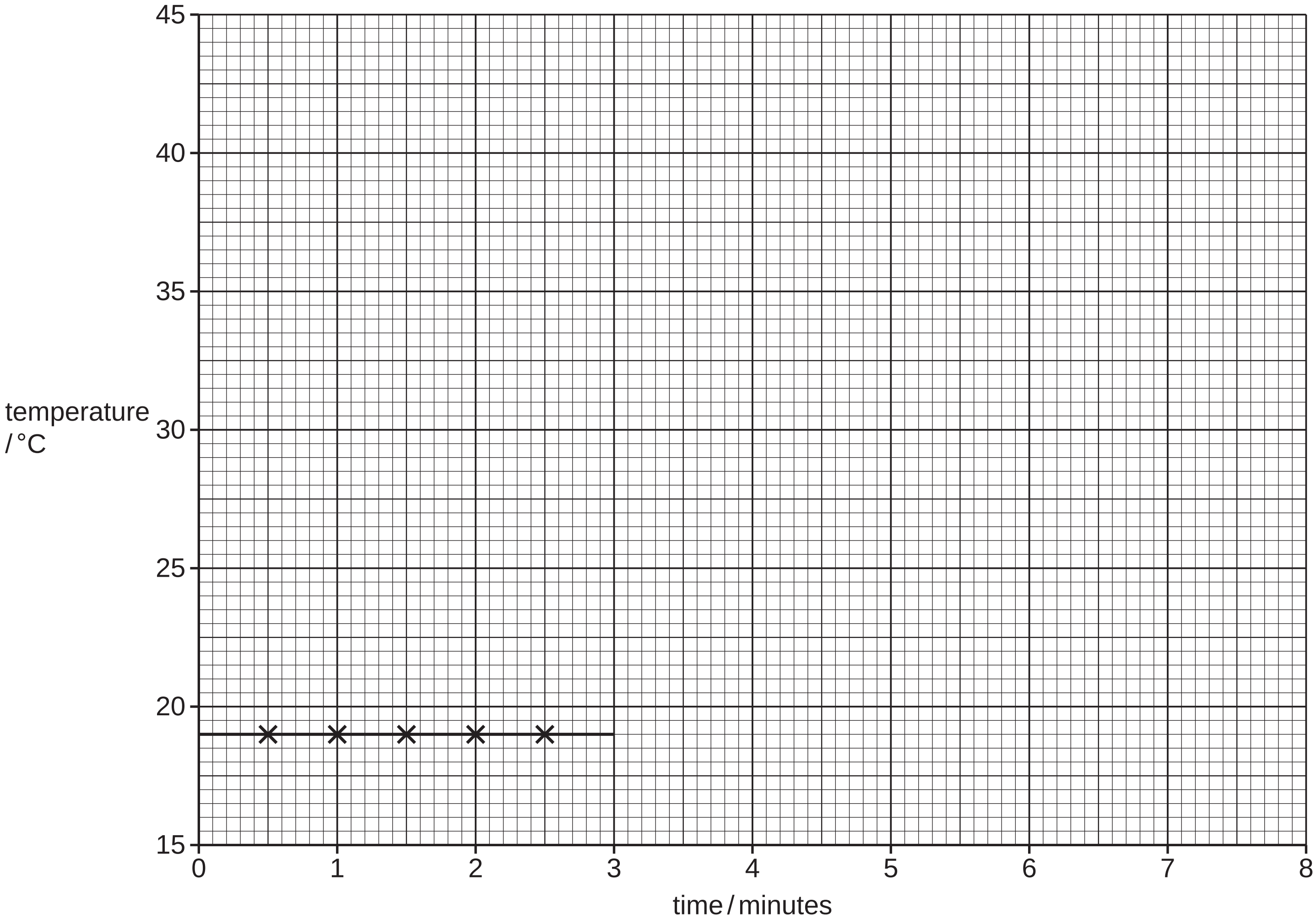


Fig. 1.1

[2]

(ii) Use your graph to determine the theoretical temperature increase at 3.0 minutes.

theoretical temperature increase at 3.0 minutes = ... °C [1]

(f) Suggest why the temperature measured at 3.5 minutes is lower than the temperature measured at 4.0 minutes.

.... [1]

(g) A student carries out experiment 2 and determines a temperature increase of 62.0 °C. The heat released by the reaction, q, is given by:

$$q = mc\Delta T$$

where m is the mass of $HCl(aq)$. Assume that $1.00\,cm^3$ of $HCl(aq)$ has a mass of 1.00 g and that the specific heat capacity of the solution, c, is $4.18\,J\,g^{-1}\,K^{-1}$.

Calculate q, in J, for experiment 2 and hence determine ΔH_2 in $kJ\,mol^{-1}$.

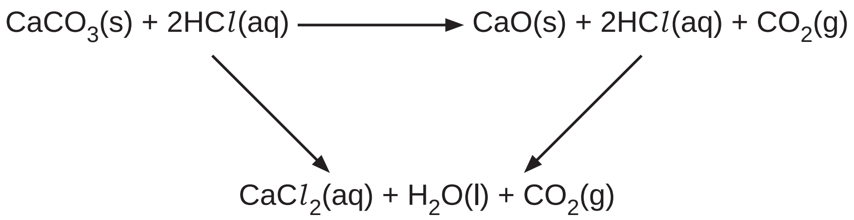
q = ... J

ΔH_2 = ... $kJ\,mol^{-1}$
[2]

(h) Use the energy cycle below, your answer to **(g)** and the information given to determine ΔH_r for the thermal decomposition of $CaCO_3$.

Enthalpy change for experiment 1, $\Delta H_1 = -84\,kJ\,mol^{-1}$.

(If you were unable to calculate a final answer in **(g)**, assume a value of $179\,kJ\,mol^{-1}$. This is **not** the correct answer and the sign has been omitted.)



ΔH_r = ... $kJ\,mol^{-1}$ [1]

(i) Identify the main weakness of the experimental procedure and suggest **one** improvement to overcome this weakness. The main weakness is **not** the type of thermometer used.

main weakness ....

improvement ....

....
[2]

[Total: 15]

2 This question is about an experiment to investigate the effect of temperature on the equilibrium constant, K_1, of the reaction shown.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

The data collected is used to determine the value of the enthalpy change of the reaction.

To set up the equilibrium, aqueous iron(III) nitrate, $Fe(NO_3)_3(aq)$, is mixed with aqueous potassium thiocyanate, KSCN(aq). Aqueous iron thiocyanate ions, $FeSCN^{2+}(aq)$, have a red colour.

A colorimeter is used to measure the absorbance of the reaction mixture. A calibration graph can then be used to determine the concentration of $FeSCN^{2+}(aq)$ in the reaction mixture.

Table 2.1 shows the solutions for the experiments.

Table 2.1

solution	ion	concentration / mol dm^{-3}
A	$SCN^{-}(aq)$	0.00920
B	$SCN^{-}(aq)$	0.00200
C	$Fe^{3+}(aq)$	0.00200
D	$Fe^{3+}(aq)$	0.500

(a) Describe how you would prepare 100.0 cm^3 of solution **B** from solution **A**.

Include a calculation of the volume of solution **A** required for the preparation of solution **B**. Give the name and capacity of any key apparatus that should be used.

Write your answer as a series of numbered steps.

....

....

....

....

....

....

.... [3]

(b) Before starting the experiment, solutions **B** and **D** are used to produce a calibration graph. Known volumes of each solution are added together and the absorbance for each mixture is recorded. The calibration graph is shown in Fig. 2.1.

The concentration of solution **D** is much greater than the concentration of solution **B** in order that solution **D** is in excess. Suggest a reason why solution **D** is in excess.

.... [1]

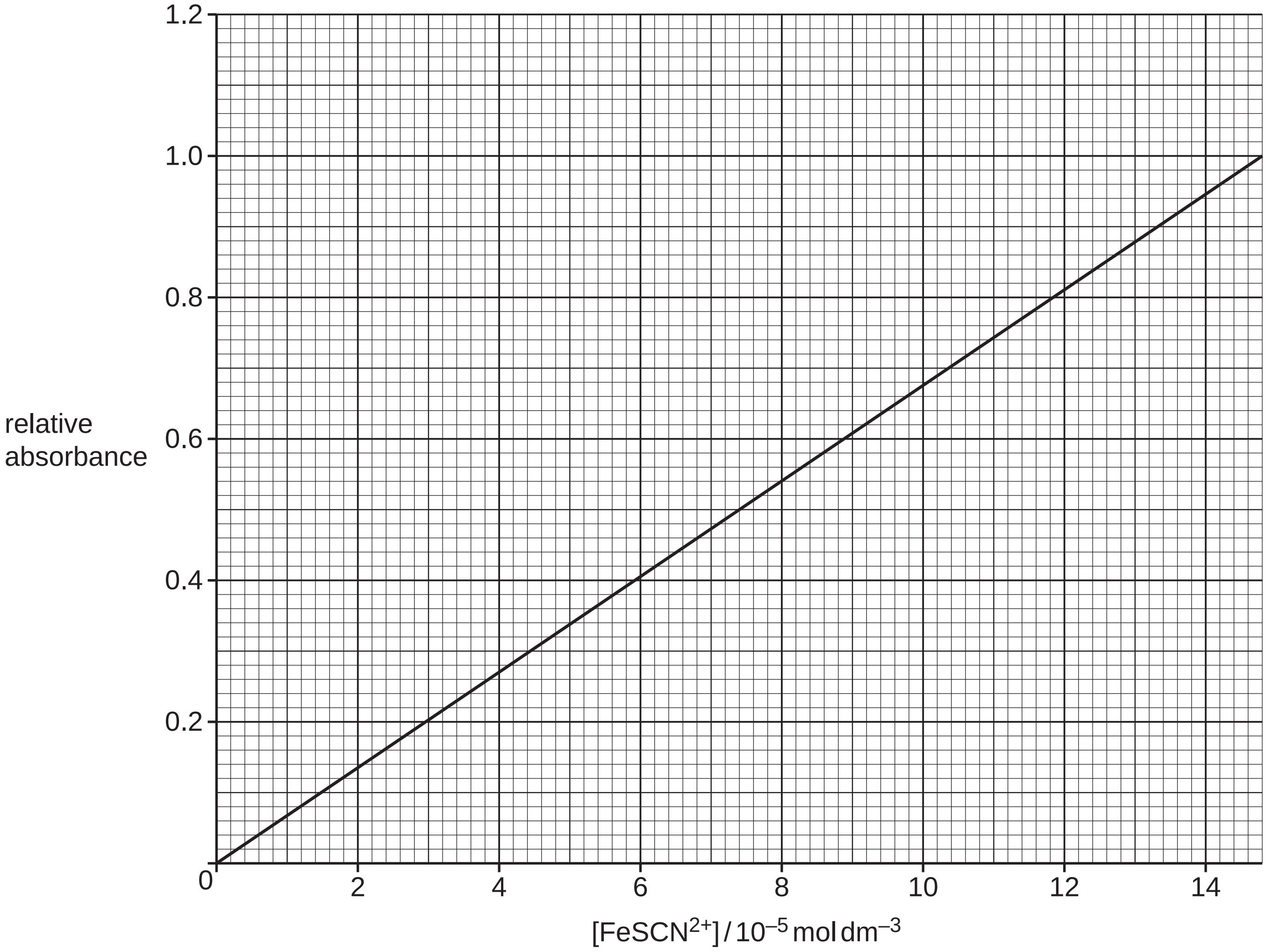


Fig. 2.1

(c) The following experimental procedure is used.

step 1 Half-fill a large beaker with water at room temperature (25 °C).

step 2 Transfer about 40 cm^3 of solution **B** into a boiling tube and place the boiling tube in the beaker of water.

step 3 Transfer 5.00 cm^3 of solution **C** into a test-tube and place the test-tube in the beaker of water.

step 4 Wait for 10 minutes.

step 5 Transfer 5.00 cm^3 of solution **B** from the boiling tube to the test-tube containing solution **C**. Stir the mixture in the test-tube and record the temperature of the mixture.

step 6 Measure the absorbance of the mixture in the test-tube using the colorimeter.

Change the temperature of the water in the beaker and repeat **steps 3** to **6** for different temperatures.

(i) Identify the dependent variable.

.... [1]

(ii) Describe how you would adjust the temperature of the water in the large beaker to obtain a temperature of 10 °C.

.... [1]

(d) A student obtains the results given in Table 2.2.

Table 2.2

1	2	3	4
temperature / °C	relative absorbance	$[FeSCN^{2+}] / 10^{-5}\ mol\ dm^{-3}$	K_1
25	0.60		
55	0.42		

The value of the equilibrium constant, K_1, can be determined using equation 1.

$$\text{equation 1} \qquad K_1 = \frac{x}{(0.0010 - x)^2}$$

x is the value of $[FeSCN^{2+}]$ in $mol\ dm^{-3}$.

(i) Use the calibration graph in Fig. 2.1 to complete column 3 in Table 2.2.
Record values to **one** decimal place. [1]

(ii) Use equation 1 to complete column 4 in Table 2.2.
Record values to the nearest whole number. [1]

(e) Another student does the same experiment for seven different temperatures, plots a graph and draws the line of best fit, as shown in Fig. 2.2.

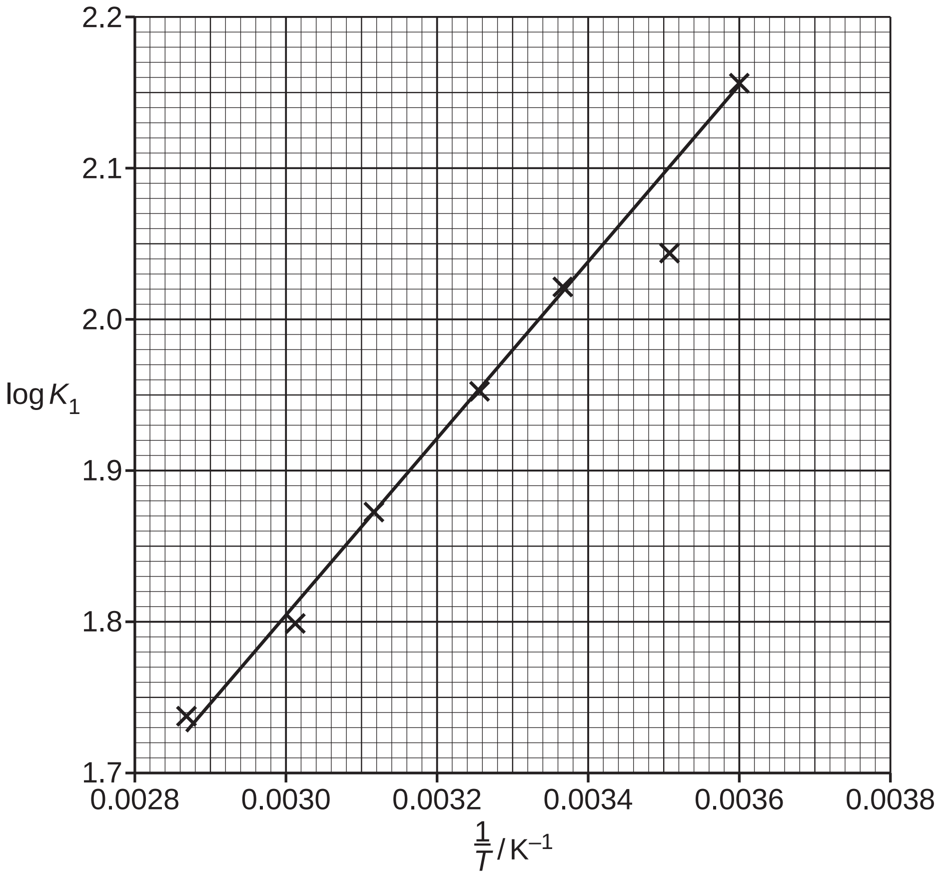


Fig. 2.2

Theory predicts that the relationship between K_1 and T is given by equation 2.

equation 2 $$\log K_1 = \frac{-\Delta H}{2.303RT} + \text{constant}$$

ΔH is the enthalpy change of reaction and T is the temperature in Kelvin.

(i) Explain why the graph supports the relationship between K_1 and T given in equation 2.

.... [1]

(ii) Circle the point on the graph in Fig. 2.2 that you consider to be most anomalous.

There were no errors in the measurements in the experiment.

A student correctly suggests that the anomaly was caused because the absorbance was lower than expected by the line of best fit. Suggest why the absorbance was lower than expected.

....

.... [2]

(iii) Determine the gradient of the line of best fit in Fig. 2.2. State the coordinates of both points you use in your calculation. These must be selected from the line of best fit.
Give the gradient to **three** significant figures.

coordinates 1 .... coordinates 2 ....

gradient = ... K
[2]

(iv) Use the gradient calculated in **(e)(iii)** and equation 2 to calculate a value for the enthalpy change of reaction, ΔH.

equation 2 $$\log K_1 = \frac{-\Delta H}{2.303RT} + \text{constant}$$

(If you were unable to obtain an answer to **(e)(iii)**, then use the value 635 K. This is **not** the correct answer.)

ΔH = ... kJ mol^{-1} [2]

[Total: 15]

Important values, constants and standards

molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
Faraday constant	$F = 9.65 \times 10^{4}\,\mathrm{C\,mol^{-1}}$
Avogadro constant	$L = 6.022 \times 10^{23}\,\mathrm{mol^{-1}}$
electronic charge	$e = -1.60 \times 10^{-19}\,\mathrm{C}$
molar volume of gas	$V_m = 22.4\,\mathrm{dm^3\,mol^{-1}}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,\mathrm{dm^3\,mol^{-1}}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,\mathrm{mol^2\,dm^{-6}}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,\mathrm{kJ\,kg^{-1}\,K^{-1}}$ ($4.18\,\mathrm{J\,g^{-1}\,K^{-1}}$)

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

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	3	4	5	6	7	8	9	10	11	12	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 –