



# Cambridge International AS & A Level

CANDIDATE  
NAME

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CENTRE  
NUMBER

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NUMBER

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**CHEMISTRY**

**9701/51**

Paper 5 Planning, Analysis and Evaluation

**May/June 2023**

**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 **16** pages. Any blank pages are indicated.

- 1 The partition coefficient,  $K_{pc}$ , shows the distribution of a solute between two immiscible solvents.  $K_{pc}$  is determined by measuring the concentration of the solute in each solvent.

The organic solvent ethoxyethane,  $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$ , and water are immiscible. A student is asked to find  $K_{pc}$  of butanedioic acid,  $\text{HOOCCH}_2\text{CH}_2\text{COOH}$ , between ethoxyethane and water.

The expression for  $K_{pc}$  when butanedioic acid is in equilibrium between ethoxyethane and water is shown.

$$K_{pc} = \frac{[\text{HOOCCH}_2\text{CH}_2\text{COOH}(\text{ethoxyethane})]}{[\text{HOOCCH}_2\text{CH}_2\text{COOH}(\text{aq})]}$$

[density: ethoxyethane,  $0.71 \text{ g cm}^{-3}$ ; water,  $1.00 \text{ g cm}^{-3}$ ]

The student uses the following method to find the partition coefficient. A diagram of the apparatus is shown in Fig. 1.1.

- step 1** Add  $30.0 \text{ cm}^3$  of distilled water to a separating funnel.
- step 2** Weigh by difference  $2.81 \text{ g}$  of butanedioic acid into the separating funnel.
- step 3** Stopper the separating funnel and shake it until the butanedioic acid has dissolved.
- step 4** Remove the stopper and add  $30.0 \text{ cm}^3$  of ethoxyethane to the separating funnel.
- step 5** Replace the stopper and shake the separating funnel gently.
- step 6** Place the separating funnel into a clamp. Allow the liquids to settle so that the two layers can be seen.
- step 7** Remove the stopper and open the separating funnel tap to allow the lower layer to run into a beaker labelled **A**. Run the upper layer into a beaker labelled **B**.
- step 8** Transfer  $10.0 \text{ cm}^3$  of the aqueous layer into a conical flask. Titrate with  $0.500 \text{ mol dm}^{-3}$   $\text{NaOH}(\text{aq})$ . Use thymolphthalein as the indicator.
- step 9** Take  $10.0 \text{ cm}^3$  of the ethoxyethane layer and add  $10.0 \text{ cm}^3$  of water to it. Titrate this mixture with  $0.100 \text{ mol dm}^{-3}$   $\text{NaOH}(\text{aq})$ . Use thymolphthalein as the indicator.

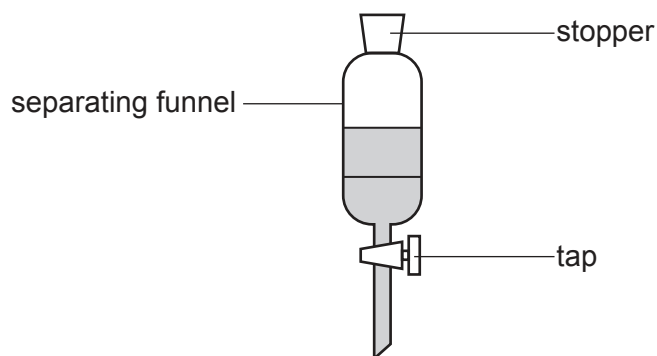


Fig. 1.1

(a) (i) State whether beaker **A** in step 7 contains the aqueous layer or the ethoxyethane layer.

Explain your answer.

Beaker **A** contains the ..... layer.

explanation .....

.....

[1]

(ii) Identify the piece of apparatus that should be used in step 8 to transfer 10.0 cm<sup>3</sup> of the aqueous layer.

..... [1]

(iii) Suggest why water is added to the ethoxyethane layer in step 9 before the titration can take place.

.....

..... [1]

- (b) For a 2.81 g sample of butanedioic acid, the titre for the aqueous layer is  $27.25 \text{ cm}^3$  and the titre for the ethoxyethane layer is  $22.50 \text{ cm}^3$ .

The equation for the reaction between butanedioic acid and sodium hydroxide is shown.



- (i) Calculate the concentration of butanedioic acid in the aqueous layer.

concentration of butanedioic acid = .....  $\text{mol dm}^{-3}$  [1]

- (ii) Calculate the partition coefficient,  $K_{\text{pc}}$ .

$K_{\text{pc}} = \dots\dots\dots$  [2]

(iii) Explain why the student is only able to repeat the titration in step 8 once.

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

(iv) Suggest how you would modify the procedure to ensure the student can repeat the titration in step 8 more than once.

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

(v) A different student forgets to shake the separating funnel in step 5.

Describe the effect this would have on the calculated  $K_{pc}$  value. Explain your answer.

effect on  $K_{pc}$  .....  
explanation .....  
..... [1]

[Total: 9]

- 2 Paper chromatography can be used to separate the individual amino acids formed when tripeptides are hydrolysed.

One molecule of a tripeptide produces three amino acid molecules when hydrolysed.

A student is asked to identify the amino acids formed from the hydrolysis of three different tripeptides, **A**, **B** and **C**, using paper chromatography.

Fig. 2.1 shows the results of the student's chromatography experiment.

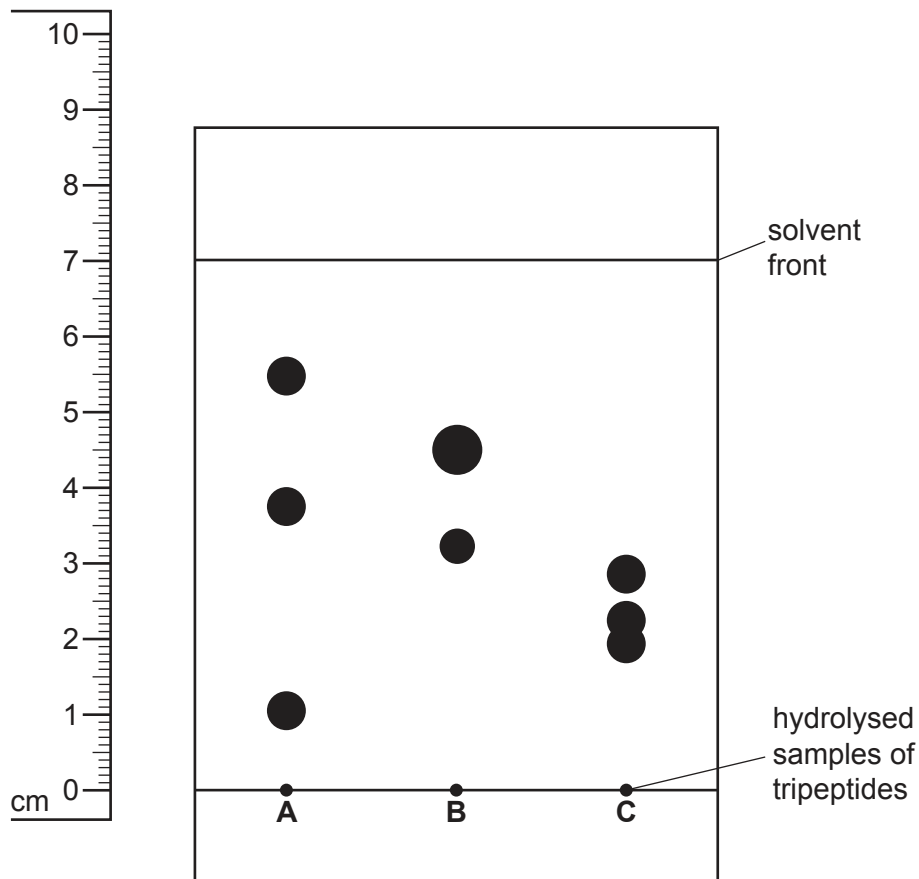


Fig. 2.1

The individual amino acids can be identified from their  $R_f$  values.

$$R_f = \frac{\text{distance travelled by the amino acid spot}}{\text{distance travelled by the solvent front}}$$

- (a) Suggest why each sample is applied to the chromatography paper using a thin capillary tube rather than a dropping pipette.

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

- (b) Suggest why it is necessary to spray a developing agent over the chromatography paper before the chromatogram can be analysed.

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

(c) Table 2.1 shows  $R_f$  values for some amino acids in the solvent used in Fig. 2.1.

**Table 2.1**

amino acid	$R_f$ value
lysine	0.14
glycine	0.26
serine	0.27
glutamic acid	0.30
alanine	0.38
proline	0.43
tryptophan	0.50
valine	0.60
leucine	0.73

Use the data in Table 2.1 to identify the amino acids in tripeptide **A**.

.....  
 ..... [2]

(d) Suggest why the hydrolysed sample of **B** produces only two spots.

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

(e) Two of the spots from the hydrolysed sample of **C** overlap.

(i) State the reason for the overlap.

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

(ii) Suggest an improvement to the method that would allow the overlapping spots to be distinguished clearly.

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

[Total: 7]





- 3 A scientist is asked to find the rate of decomposition of an aromatic diazonium compound and determine the order of the reaction with respect to the aromatic diazonium compound.

(a) The scientist is given 1.02 g of an aromatic diazonium compound in a 50 cm<sup>3</sup> beaker.

Describe the steps the scientist should take to make a 100.0 cm<sup>3</sup> standard solution containing 1.02 g of this compound.

Give the name and capacity of the apparatus the scientist should use.

Write your answer using a series of numbered steps.

.....

.....

.....

.....

.....

.....

.....

.....

..... [3]

(b) Benzenediazonium chloride, an aromatic diazonium compound, decomposes in solution to produce phenol and nitrogen gas. The scientist warms 50 cm<sup>3</sup> of the solution to 50 °C. The scientist records the volume of nitrogen gas produced at different times during the decomposition.

(i) Identify the piece of apparatus that should be used to maintain the temperature of the solution.

..... [1]

(ii) Identify the dependent variable.

..... [1]

(iii) Suggest why the scientist does **not** monitor the reaction by measuring the loss in mass.

.....

..... [1]

(c) Table 3.1 shows the results of the experiment.

**Table 3.1**

time, $t/\text{min}$	volume, $V_t/\text{cm}^3$	$V_{\text{final}} - V_t/\text{cm}^3$
0	0.0	
5	17.3	
9	27.0	
16	39.5	
21	42.6	
28	49.0	
36	52.8	
final	57.2	0.0

$V_{\text{final}}$  is the final volume of nitrogen gas measured once the decomposition is complete.

$V_t$  is the volume collected at time =  $t$ .

$V_{\text{final}} - V_t$  is proportional to the concentration of the benzenediazonium chloride.

(i) Complete Table 3.1. [1]

(ii) Plot a graph on the grid in Fig. 3.1 to show the relationship between  $V_{\text{final}} - V_t$  and time. Use a cross ( $\times$ ) to plot each data point.

Draw a curved line of best fit through the plotted points.

[2]

(iii) Circle the **one** point on the graph that you consider to be most anomalous. [1]

(iv) Suggest **one** reason to explain the anomalous point you have circled.

Assume no error was made in the measurement of volume.

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

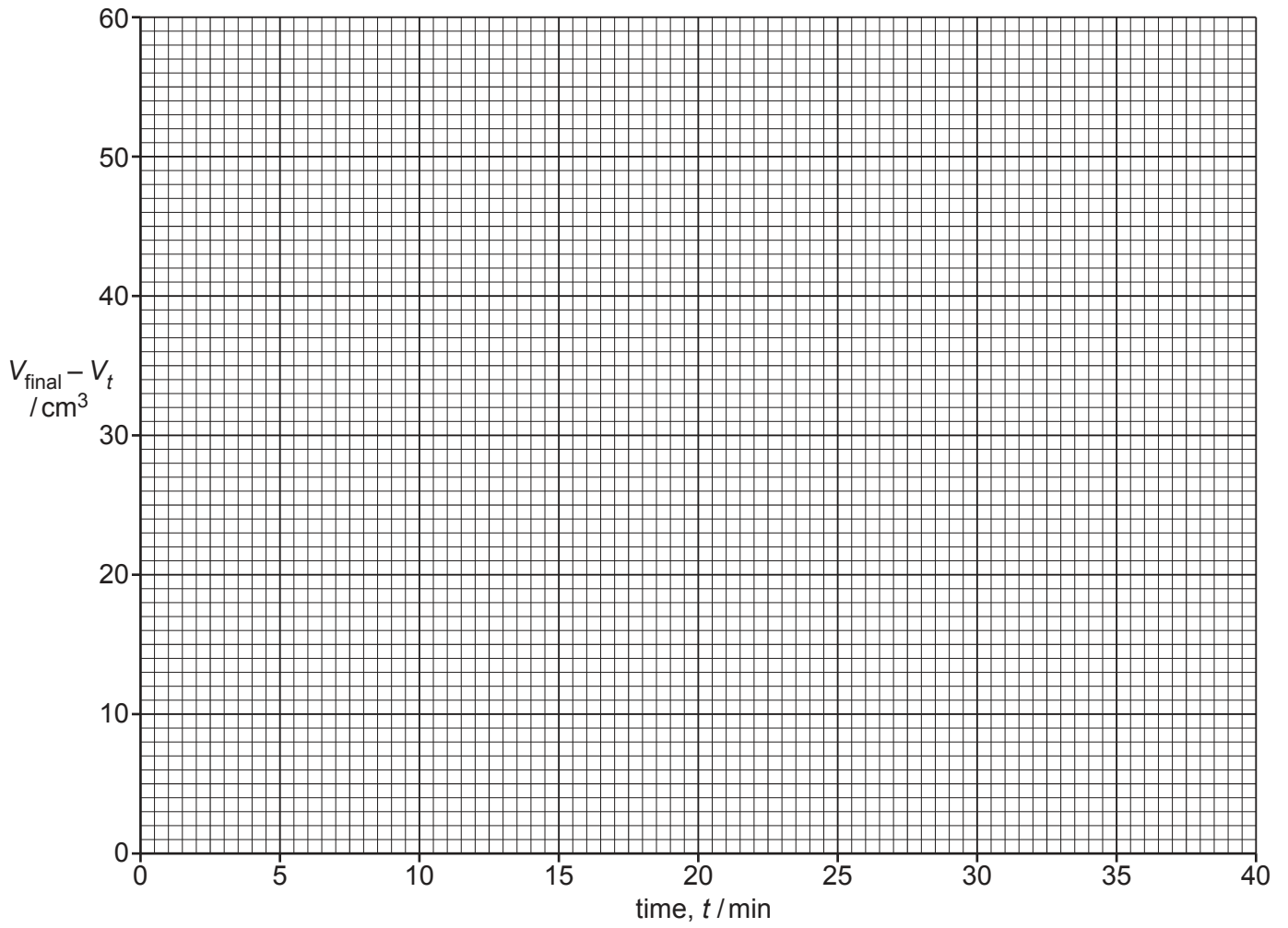


Fig. 3.1

- (v) Use your graph to find the first two successive half-lives,  $t_{1/2}$ , for this reaction.

State the coordinates of both points you used in each of your calculations.

first  $t_{1/2}$ : coordinates ..... and .....

half-life = ..... min

second  $t_{1/2}$ : coordinates ..... and .....

half-life = ..... min

[2]

- (vi) Use your answer to (c)(v) to state the order of the reaction with respect to the benzenediazonium chloride. Explain your answer.

If you were unable to obtain an answer to (c)(v) you may use the values 8.6 min and 11.0 min for the half-lives. These are **not** the correct values.

order = .....

explanation .....

.....

[1]

[Total: 14]





**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 $\text{J g}^{-1} \text{ K}^{-1}$ )

## The Periodic Table of Elements

		Group															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">1 H hydrogen 1.0</div> <div style="border: 1px solid black; padding: 2px;">2 He helium 4.0</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">3 Li lithium 6.9</div> <div style="border: 1px solid black; padding: 2px;">4 Be beryllium 9.0</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">5 B boron 10.8</div> <div style="border: 1px solid black; padding: 2px;">6 C carbon 12.0</div> <div style="border: 1px solid black; padding: 2px;">7 N nitrogen 14.0</div> <div style="border: 1px solid black; padding: 2px;">8 O oxygen 16.0</div> <div style="border: 1px solid black; padding: 2px;">9 F fluorine 19.0</div> <div style="border: 1px solid black; padding: 2px;">10 Ne neon 20.2</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">11 Na sodium 23.0</div> <div style="border: 1px solid black; padding: 2px;">12 Mg magnesium 24.3</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">13 Al aluminium 27.0</div> <div style="border: 1px solid black; padding: 2px;">14 Si silicon 28.1</div> <div style="border: 1px solid black; padding: 2px;">15 P phosphorus 31.0</div> <div style="border: 1px solid black; padding: 2px;">16 S sulfur 32.1</div> <div style="border: 1px solid black; padding: 2px;">17 Cl chlorine 35.5</div> <div style="border: 1px solid black; padding: 2px;">18 Ar argon 39.9</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">19 K potassium 39.1</div> <div style="border: 1px solid black; padding: 2px;">20 Ca calcium 40.1</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">21 Sc scandium 45.0</div> <div style="border: 1px solid black; padding: 2px;">22 Ti titanium 47.9</div> <div style="border: 1px solid black; padding: 2px;">23 V vanadium 50.9</div> <div style="border: 1px solid black; padding: 2px;">24 Cr chromium 52.0</div> <div style="border: 1px solid black; padding: 2px;">25 Mn manganese 54.9</div> <div style="border: 1px solid black; padding: 2px;">26 Fe iron 55.8</div> <div style="border: 1px solid black; padding: 2px;">27 Co cobalt 58.9</div> <div style="border: 1px solid black; padding: 2px;">28 Ni nickel 58.7</div> <div style="border: 1px solid black; padding: 2px;">29 Cu copper 63.5</div> <div style="border: 1px solid black; padding: 2px;">30 Zn zinc 65.4</div> <div style="border: 1px solid black; padding: 2px;">31 Ga gallium 69.7</div> <div style="border: 1px solid black; padding: 2px;">32 Ge germanium 72.6</div> <div style="border: 1px solid black; padding: 2px;">33 As arsenic 74.9</div> <div style="border: 1px solid black; padding: 2px;">34 Se selenium 79.0</div> <div style="border: 1px solid black; padding: 2px;">35 Br bromine 79.9</div> <div style="border: 1px solid black; padding: 2px;">36 Kr krypton 83.8</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">37 Rb rubidium 85.5</div> <div style="border: 1px solid black; padding: 2px;">38 Sr strontium 87.6</div> <div style="border: 1px solid black; padding: 2px;">39 Y yttrium 88.9</div> <div style="border: 1px solid black; padding: 2px;">40 Zr zirconium 91.2</div> <div style="border: 1px solid black; padding: 2px;">41 Nb niobium 92.9</div> <div style="border: 1px solid black; padding: 2px;">42 Mo molybdenum 95.9</div> <div style="border: 1px solid black; padding: 2px;">43 Tc technetium —</div> <div style="border: 1px solid black; padding: 2px;">44 Ru ruthenium 101.1</div> <div style="border: 1px solid black; padding: 2px;">45 Rh rhodium 102.9</div> <div style="border: 1px solid black; padding: 2px;">46 Pd palladium 106.4</div> <div style="border: 1px solid black; padding: 2px;">47 Ag silver 107.9</div> <div style="border: 1px solid black; padding: 2px;">48 Cd cadmium 112.4</div> <div style="border: 1px solid black; padding: 2px;">49 In indium 114.8</div> <div style="border: 1px solid black; padding: 2px;">50 Sn tin 118.7</div> <div style="border: 1px solid black; padding: 2px;">51 Sb antimony 121.8</div> <div style="border: 1px solid black; padding: 2px;">52 Te tellurium 127.6</div> <div style="border: 1px solid black; padding: 2px;">53 I iodine 126.9</div> <div style="border: 1px solid black; padding: 2px;">54 Xe xenon 131.3</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">55 Cs caesium 132.9</div> <div style="border: 1px solid black; padding: 2px;">56 Ba barium 137.3</div> <div style="border: 1px solid black; padding: 2px;">57–71 lanthanoids —</div> <div style="border: 1px solid black; padding: 2px;">72 Hf hafnium 178.5</div> <div style="border: 1px solid black; padding: 2px;">73 Ta tantalum 180.9</div> <div style="border: 1px solid black; padding: 2px;">74 W tungsten 183.8</div> <div style="border: 1px solid black; padding: 2px;">75 Re rhenium 186.2</div> <div style="border: 1px solid black; padding: 2px;">76 Os osmium 190.2</div> <div style="border: 1px solid black; padding: 2px;">77 Ir iridium 192.2</div> <div style="border: 1px solid black; padding: 2px;">78 Pt platinum 195.1</div> <div style="border: 1px solid black; padding: 2px;">79 Au gold 197.0</div> <div style="border: 1px solid black; padding: 2px;">80 Hg mercury 200.6</div> <div style="border: 1px solid black; padding: 2px;">81 Tl thallium 204.4</div> <div style="border: 1px solid black; padding: 2px;">82 Pb lead 207.2</div> <div style="border: 1px solid black; padding: 2px;">83 Bi bismuth 209.0</div> <div style="border: 1px solid black; padding: 2px;">84 Po polonium —</div> <div style="border: 1px solid black; padding: 2px;">85 At astatine —</div> <div style="border: 1px solid black; padding: 2px;">86 Rn radon —</div> </div>															
		<div style="display: flex; justify-content: space-between; align-items: center;"> <div style="border: 1px solid black; padding: 2px;">87 Fr francium —</div> <div style="border: 1px solid black; padding: 2px;">88 Ra radium —</div> <div style="border: 1px solid black; padding: 2px;">89–103 actinoids —</div> <div style="border: 1px solid black; padding: 2px;">104 Rf rutherfordium —</div> <div style="border: 1px solid black; padding: 2px;">105 Db dubnium —</div> <div style="border: 1px solid black; padding: 2px;">106 Sg seaborgium —</div> <div style="border: 1px solid black; padding: 2px;">107 Bh bohrium —</div> <div style="border: 1px solid black; padding: 2px;">108 Hs hassium —</div> <div style="border: 1px solid black; padding: 2px;">109 Mt meitnerium —</div> <div style="border: 1px solid black; padding: 2px;">110 Ds darmstadtium —</div> <div style="border: 1px solid black; padding: 2px;">111 Rg roentgenium —</div> <div style="border: 1px solid black; padding: 2px;">112 Cn copernicium —</div> <div style="border: 1px solid black; padding: 2px;">113 Nh nihonium —</div> <div style="border: 1px solid black; padding: 2px;">114 Fl flerovium —</div> <div style="border: 1px solid black; padding: 2px;">115 Mc moscovium —</div> <div style="border: 1px solid black; padding: 2px;">116 Lv livermorium —</div> <div style="border: 1px solid black; padding: 2px;">117 Ts tennessine —</div> <div style="border: 1px solid black; padding: 2px;">118 Og oganeson —</div> </div>															

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	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 —