



# Cambridge International AS & A Level

CANDIDATE  
NAME



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## CHEMISTRY

9701/51

Paper 5 Planning, Analysis and Evaluation

May/June 2025

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

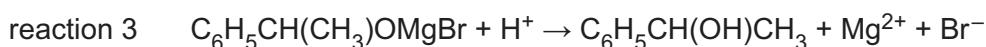
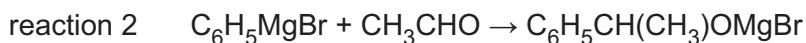
- The total mark for this paper is 30.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **12** pages.



1 Grignard reagents have the general formula  $\text{RMgX}$ , where R is a hydrocarbon group and X is a halogen. The Grignard reagent  $\text{C}_6\text{H}_5\text{MgBr}$  is used as an intermediate in the reaction between bromobenzene,  $\text{C}_6\text{H}_5\text{Br}$ , and ethanal,  $\text{CH}_3\text{CHO}$ , to prepare 1-phenylethanol,  $\text{C}_6\text{H}_5\text{CH}(\text{OH})\text{CH}_3$ . An organic solvent, ethoxyethane, is used.

The equations for the three reactions that take place during the preparation are shown.



The preparation involves the following steps.

**step 1** Set up the apparatus shown in Fig. 1.1 with approximately 1.25 g of Mg powder and  $5\text{ cm}^3$  of ethoxyethane in the round-bottomed flask.

**step 2** Add 0.0500 mol of liquid  $\text{C}_6\text{H}_5\text{Br}$  to the round-bottomed flask dropwise using the tap funnel. Leave until reaction 1 is complete.

**step 3** Dissolve 3.00  $\text{cm}^3$  of  $\text{CH}_3\text{CHO}$  in  $15\text{ cm}^3$  of ethoxyethane and add this solution to the round-bottomed flask using the tap funnel. Leave until reaction 2 is complete.

**step 4** Remove the condenser, tube Y and the tap funnel from the round-bottomed flask.

**step 5** Add  $40\text{ cm}^3$  of dilute hydrochloric acid,  $\text{HCl}(\text{aq})$ , to the round-bottomed flask so that reaction 3 takes place.

**step 6** Transfer the contents of the round-bottomed flask to a separating funnel. Allow the liquids to settle so that two layers are formed.

**step 7** Open the tap of the separating funnel and run the lower layer into a beaker labelled **A**. Run the upper layer into a beaker labelled **B**.

**step 8** Allow the ethoxyethane to evaporate from the beaker containing  $\text{C}_6\text{H}_5\text{CH}(\text{OH})\text{CH}_3$ .

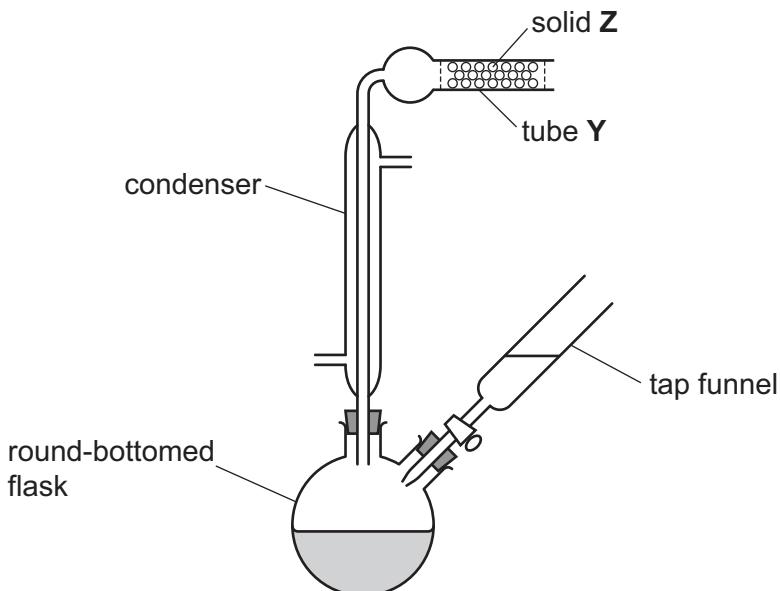


Fig. 1.1





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Some relevant data are shown in Table 1.1.

Table 1.1

substance	density /g cm <sup>-3</sup>	boiling point /°C	hazard
bromobenzene	1.50	156	flammable, toxic, skin irritant
distilled water	1.00	100	non-hazardous
ethoxyethane	0.714	35	flammable, toxic
ethanal	0.788	21	flammable, eye and respiratory irritant
1-phenylethanol	1.01	204	flammable, toxic, eye irritant

(a) Use the information in Table 1.1 to suggest why the following safety precautions are used.

- wearing chemically resistant gloves

.....

- using a fume hood

.....

[2]

(b) Dry apparatus and reagents are essential for steps 1–3.

(i) Suggest how the glassware shown in Fig. 1.1 should be dried before use in step 1.

.....

[1]

(ii) The ethoxyethane contains a small amount of water.

Suggest how the water can be removed from the ethoxyethane before use in steps 1 and 3.

.....

[1]

(c) Fig. 1.1 shows the apparatus for steps 1–3.

(i) Draw a labelled arrow on Fig. 1.1 to show where the water enters the condenser. [1]

(ii) Suggest why solid Z is used.

.....

[1]

(iii) Give **one** reason why the apparatus does **not** have a bung at the end of tube Y.

.....

[1]





(d) In step 1, approximately 1.25 g of Mg powder is needed.

Outline how the student should accurately weigh by difference using a weighing boat so that the exact mass of Mg transferred into the flask is known. Include a results table, with appropriate headings, ready for the student to fill in.

.....  
.....  
.....

[2]

(e) Use the information in Table 1.1 to determine the volume, in  $\text{cm}^3$ , of bromobenzene used in step 2.

[ $M_r$ :  $\text{C}_6\text{H}_5\text{Br}$ , 156.9]

volume of  $\text{C}_6\text{H}_5\text{Br}$  = .....  $\text{cm}^3$  [1]

(f) The bromobenzene is added dropwise in step 2.

Suggest **one** reason why the bromobenzene is **not** added all at once.

..... [1]

(g) Suggest why a measuring cylinder is a suitable piece of apparatus to measure  $40 \text{ cm}^3$  of hydrochloric acid in step 5.

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





(h) The separating funnel used in steps 6 and 7 is shown in Fig. 1.2. The final product, 1-phenylethanol, is in the ethoxyethane layer.

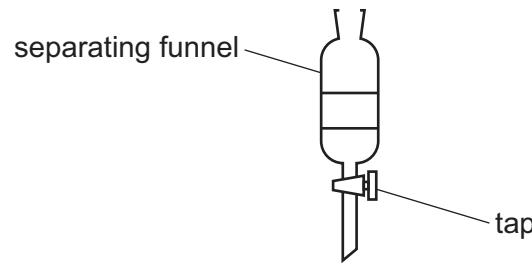


Fig. 1.2

State whether beaker **A** or beaker **B** contains the layer with 1-phenylethanol after step 7. Explain your answer using the information given in Table 1.1.

beaker .....

explanation .....

..... [1]





(i) The overall reaction can be represented as shown in Fig. 1.3.

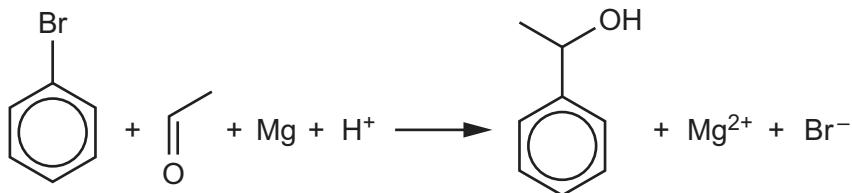


Fig. 1.3

(i) At the end of step 8, 2.17 g of 1-phenylethanol is obtained. Determine whether bromobenzene or ethanal is the limiting reagent and hence calculate the percentage yield of 1-phenylethanol. Show your working.

[ $M_r$ : C<sub>6</sub>H<sub>5</sub>CH(OH)CH<sub>3</sub>, 122.0]

percentage yield of C<sub>6</sub>H<sub>5</sub>CH(OH)CH<sub>3</sub> = ..... % [2]

(ii) Suggest why the infrared spectrum of the product detected the presence of a C=O peak.

..... [1]

[Total: 16]

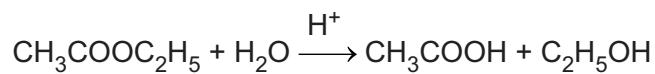




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2 An experiment is carried out to determine the rate constant,  $k$ , for the hydrolysis of ethyl ethanoate,  $\text{CH}_3\text{COOC}_2\text{H}_5$ , using a hydrochloric acid,  $\text{HCl}(\text{aq})$ , catalyst.

The equation for the reaction is shown.



The rate equation for this reaction is shown.

$$\text{rate of reaction} = k [\text{CH}_3\text{COOC}_2\text{H}_5]$$

The progress of the reaction is followed by determining how the concentration of acid changes with time.

A portion of the reaction mixture is removed every 5 minutes and titrated with sodium hydroxide,  $\text{NaOH}(\text{aq})$ . A final titration is carried out after 180 minutes.

A student carries out the following steps.

**step 1** Add  $70\text{ cm}^3$  of iced water to seven separate small conical flasks. Add a few drops of phenolphthalein indicator to each flask. Phenolphthalein is pink in alkaline conditions and colourless in acidic conditions.

**step 2** Use a measuring cylinder to transfer  $100\text{ cm}^3$  of  $0.200\text{ mol dm}^{-3}$   $\text{HCl}(\text{aq})$  into a large conical flask.

**step 3** Add  $5.00\text{ cm}^3$  of  $\text{CH}_3\text{COOC}_2\text{H}_5$  to the large conical flask and swirl the flask to mix the contents. Start a stopwatch.

**step 4** Transfer  $10.00\text{ cm}^3$  of reaction mixture to one of the small conical flasks containing the iced water and indicator. Record the time. Shake the small flask.

**step 5** Carry out a single titration of the mixture in the small conical flask using  $0.15\text{ mol dm}^{-3}$   $\text{NaOH}(\text{aq})$ .

**step 6** Repeat steps 4 and 5 at the times shown in Table 2.1 using a different small conical flask for each titration.

(a) Give **two** reasons that explain why the use of iced water in step 4 decreases the rate of reaction.

reason 1 .....

reason 2 .....

[2]

(b) Describe the observation that is used to determine the end-point of the titrations.

..... [1]





(c) The results of the experiment are shown in Table 2.1.  
 $V_t$  is the titre at a given time,  $t$ .  
 $V_\infty$  is the final titre at  $t = 180$  min when the reaction is assumed to be complete.

Table 2.1

1	2	3	4
time, $t$ /min	titre, $V_t$ /cm <sup>3</sup>	$(V_\infty - V_t)$ /cm <sup>3</sup>	$\log[(V_\infty - V_t)/\text{cm}^3]$
0	12.00		
5	16.40		
10	22.15		
15	23.45		
20	26.30		
25	28.70		
180	45.70		

(i) Complete Table 2.1.  
 Give your answers in column 3 to **two** decimal places and your answers in column 4 to **four** significant figures. [2]

(ii) Plot a graph on the grid in Fig. 2.1 to show the relationship between  $\log[(V_\infty - V_t)/\text{cm}^3]$  and time,  $t$ . Use a cross (x) to plot each data point.  
 Draw a straight line of best fit. [2]

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

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

Assume no error was made in the experimental value of the titre.

.....

..... [1]



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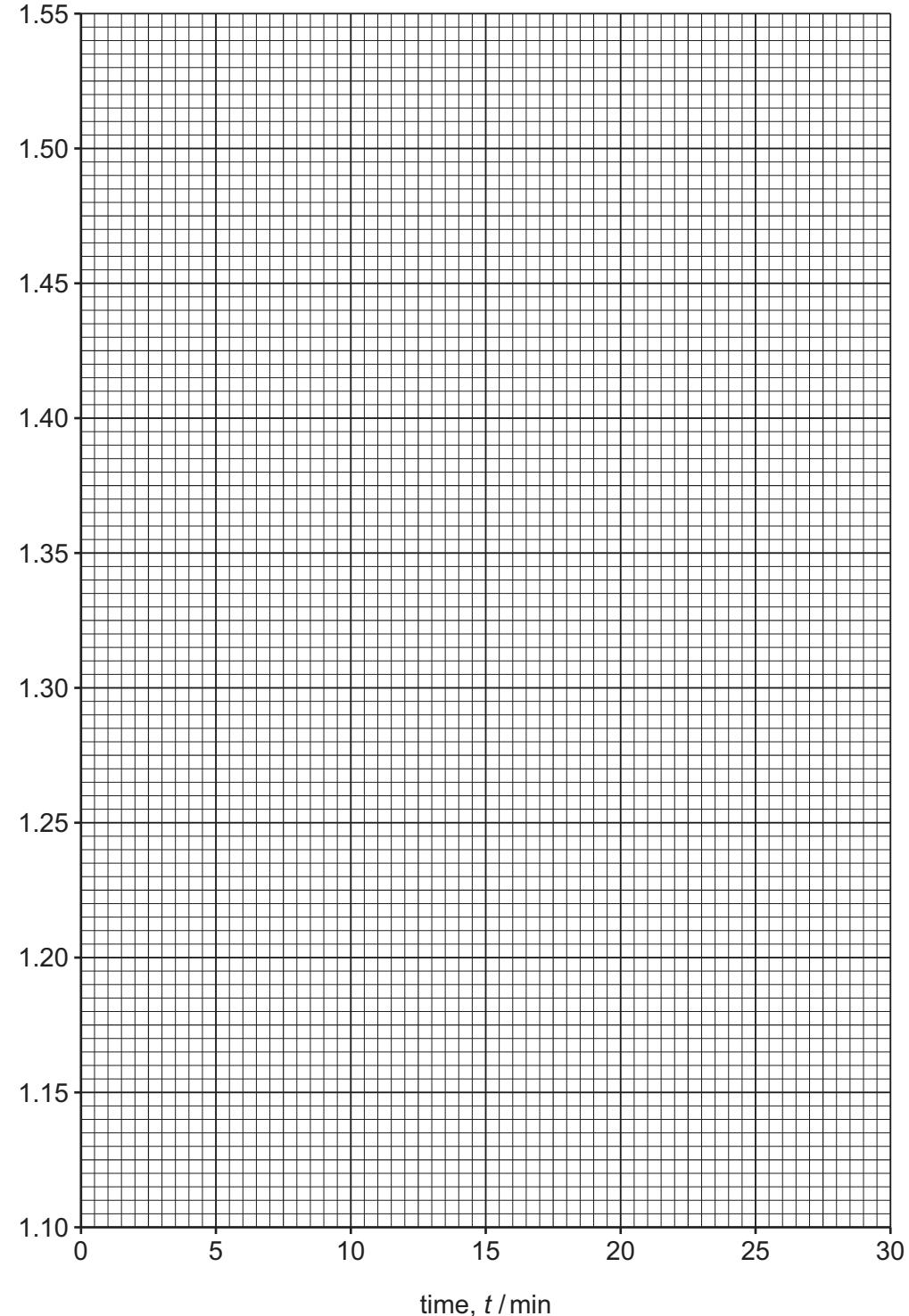


Fig. 2.1





(iv) Determine the gradient of your line of best fit in Fig. 2.1.

State the coordinates of both points you use in your calculation. These must be selected from your line of best fit.

Give the gradient to **three** significant figures.

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

gradient = .....  $\text{min}^{-1}$   
[2]

(d) The equation of the straight line plotted in Fig. 2.1 is shown.

$$\log[(V_\infty - V_t)/\text{cm}^3] = -\frac{kt}{2.303} + \text{constant}$$

Use the gradient determined in (c)(iv) to calculate a value for  $k$  in  $\text{s}^{-1}$ .

[If you were unable to determine an answer to (c)(iv), then use the value  $-0.0312 \text{ min}^{-1}$  for the gradient. This is **not** the correct answer.]

$k = \dots \text{s}^{-1}$  [2]

(e) Use your graph in Fig. 2.1 to state whether you consider the results to be reliable. Give a reason for your answer.

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

(f)  $k$  increases with temperature.

A second experiment is carried out at a higher temperature.

Sketch a suggested line of best fit on Fig. 2.1 for the second experiment. [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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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 <sup>-1</sup> K <sup>-1</sup> )





## The Periodic Table of Elements

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3	lithium	6.9	beryllium	9.0	boron	10.8	carbon	12.0	nitrogen	14.0	oxygen	16.0	fluorine	19.0	helium	4.0	11	sodium	23.0	magnesium	24.3	aluminum	27.0	silicon	28.1	phosphorus	31.0	sulfur	32.1	chlorine	35.5	argon	39.9																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
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132.9	cesium	137.3	barium	137.3	lanthanoids	178.5	hafnium	180.9	tungsten	183.8	niobium	186.2	rhodium	190.2	osmium	192.2	platinum	195.1	iridium	197.0	mercury	200.6	thallium	204.4	gold	207.2	lead	209.0	bismuth	209.0	polonium	—	astatine	—	radon	—																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
87	Fr	88	Ra	89-103	Rf	104	Db	105	Sg	106	Bh	107	Ts	108	Mt	109	Ds	110	Rg	111	Cn	112	Nh	113	Fj	114	Mc	115	Lv	116	Ts	117	OG	118	oganesseum	—	tennessine	—	oganesson	—																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu	72	lutetium	173.0	ytterbium	173.1	thulium	168.9	erbium	167.3	holmium	164.9	yttrium	157.3	gadolinium	157.3	lanthanum	138.9	cerium	140.1	praseodymium	140.9	neodymium	144.2	promethium	—	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thulium	158.9	terbium	158.9	ytterbium	157.3	europium	152.0	neptunium	150.4	cerium	144.2	praseodymium	140.9	neodymium	144.2	thul