Write your name here

Surname	Other names

Pearson Edexcel Level 3 GCE

Centre Number | Candidate Number

Chemistry

Advanced

Paper 1: Advanced Inorganic and Physical Chemistry

Sample Assessment Materials for first teaching September 2015

Time: 1 hour 45 minutes

Paper Reference
9CH0/01

You must have:
Data Booklet
Scientific calculator, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- You may use a scientific calculator.
- For questions marked with an *, marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- Show all your working in calculations and include units where appropriate.

Turn over ▶

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PEARSON

Answer ALL questions.

Write your answers in the spaces provided.

Some questions must be answered with a cross in a box ☒.
If you change your mind about an answer, put a line through the box ☒
and then mark your new answer with a cross ☒.

1 This question is about the bonding and structure of molecules.

(a) Which element exists as discrete molecules in its solid state?

(1)

☒ **A** aluminium

☒ **B** iodine

☒ **C** silicon

☒ **D** sodium

(b) Which compound has non-polar molecules?

(1)

☒ **A** ammonia

☒ **B** carbon dioxide

☒ **C** hydrogen sulfide

☒ **D** water

(c) Which is the best reason for why the boiling temperature of HF is much higher than that of HCl?

(1)

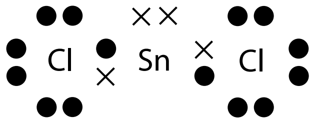
☒ **A** the instantaneous dipole-induced dipole (London) forces are stronger in HF

☒ **B** HF molecules have a smaller mass

☒ **C** there are intermolecular hydrogen bonds in HF

☒ **D** HF molecules have fewer electrons

(d) The dot-and-cross diagram for a molecule of tin(II) chloride, $SnCl_2$, in the gaseous state is:



(i) Using the electron-pair repulsion theory, explain the shape of this molecule.

(2)

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(ii) Predict a value for the Cl—Sn—Cl bond angle.

Justify your answer.

(2)

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(Total for Question 1 = 7 marks)

2 This question is about energy changes involved in the formation of ionic compounds.

(a) What is the order of increasing first ionisation energy for the elements beryllium, helium and lithium?

(1)

☒ **A** lithium < helium < beryllium

☒ **B** beryllium < lithium < helium

☒ **C** helium < beryllium < lithium

☒ **D** lithium < beryllium < helium

(b) The **second** ionisation energy of calcium has a magnitude of 1150 kJ mol^{-1}.

Which of the following represents the **second** ionisation energy of calcium?

(1)

☒ **A** $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ $\Delta H^{\ominus} = +1150$ kJ mol^{-1}

☒ **B** $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ $\Delta H^{\ominus} = +1150$ kJ mol^{-1}

☒ **C** $Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$ $\Delta H^{\ominus} = -1150$ kJ mol^{-1}

☒ **D** $Ca^+(g) \rightarrow Ca^{2+}(g) + e^-$ $\Delta H^{\ominus} = -1150$ kJ mol^{-1}

(c) The formation of potassium ions can be represented by the equation

$$K(s) \rightarrow K^+(g) + e^-$$

Which statement corresponds to the energy change for this process?

(1)

☒ **A** the first electron affinity of potassium

☒ **B** the first ionisation energy of potassium

☒ **C** the sum of the enthalpy change of atomisation of potassium and the first electron affinity of potassium

☒ **D** the sum of the enthalpy change of atomisation of potassium and the first ionisation energy of potassium

(d) The table shows the ionic radius and charge of each of six ions.

Ion	D^+	E^+	G^{2+}	X^-	Y^-	Z^{2-}
Ionic radius / nm	0.14	0.18	0.15	0.14	0.18	0.15

The ionic solids DX, EY and GZ have the same lattice structure.

Deduce the order of magnitude of their lattice energies, giving the most exothermic first.

Justify your answer.

(3)

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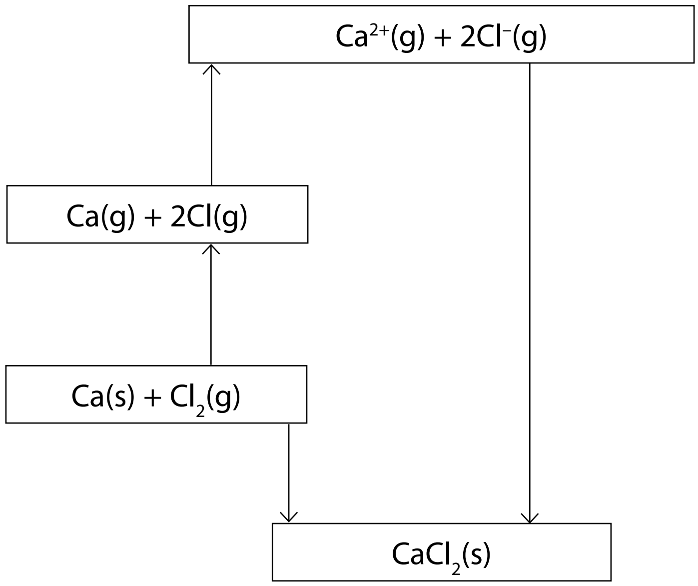
(e) The diagram shows a Born-Haber cycle for calcium chloride, $CaCl_2$.



	kJ mol^{-1}
Enthalpy of formation of $CaCl_2(s)$	–796
Lattice energy of $CaCl_2(s)$	–2258
Enthalpy of atomisation of $Ca(s) \rightarrow Ca(g)$	178
Enthalpy of atomisation of $\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$	122
First ionisation energy of Ca(g)	590
Electron affinity of Cl(g)	–349

Calculate the second ionisation energy of calcium, in kJ mol^{-1}.

(2)

(Total for Question 2 = 8 marks)

3 Vanadium is a transition metal that forms ions with several oxidation numbers. Four of these ions are shown in the table.

Formula of ion	Oxidation number of vanadium	Colour of ion
V^{2+}	+2	violet
V^{3+}	+3	green
VO^{2+}	+4	blue
VO_2^{+}	+5	yellow

(a) Complete the electronic configuration for the vanadium atom and the V^{3+} ion.

(2)

V $1s^2\ 2s^2\ 2p^6\ 3s^2$ ....

V^{3+} $1s^2\ 2s^2\ 2p^6\ 3s^2$ ....

(b) The table shows the standard electrode (redox) potentials, $E^{\ominus}$, for some half-cell reactions.

Redox system	Half-cell reaction	$E^{\ominus}$ / V
1	$V^{2+}(aq) + 2e^- \rightleftharpoons V(s)$	−1.20
2	$V^{3+}(aq) + e^- \rightleftharpoons V^{2+}(aq)$	−0.26
3	$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l)$	+0.34
4	$VO_2^+(aq) + 2H^+(aq) + e^- \rightleftharpoons VO^{2+}(aq) + H_2O(l)$	+1.00
5	$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons SO_2(g) + 2H_2O(l)$	+0.17

(i) Explain, using information from the table, the colour changes that take place when SO_2 gas is bubbled slowly through an acidified solution containing VO_2^+ ions.

Equations are not required.

(3)

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(ii) Explain, using information in the table, whether the disproportionation of $V^{2+}(aq)$ into $V^{3+}(aq)$ and V(s) is feasible under standard conditions.

(2)

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(Total for Question 3 = 7 marks)

4 Aqueous copper(II) sulfate reacts with an excess of aqueous ammonia to give a dark blue solution.

The dark blue solution contains the octahedral complex ion, $[Cu(NH_3)_x(H_2O)_y]^{2+}$.

The formula of this complex ion is determined by colorimetry, using this method:

- Make up six different mixtures of 1.00 mol dm^{-3} aqueous ammonia and 0.500 mol dm^{-3} aqueous copper(II) sulfate and water.
- Filter the mixtures to remove any precipitate that forms.
- The filtrate is a dark blue solution that contains the complex ion, $[Cu(NH_3)_x(H_2O)_y]^{2+}$.
- Place the dark blue solution into a colorimeter and measure the absorbance of the solution.

The table shows the absorbance of each mixture.

	Mixture					
	1	**2**	**3**	**4**	**5**	**6**
Volume of 0.500 mol dm^{-3} $CuSO_4$(aq) / cm^3	5.00	5.00	5.00	5.00	5.00	5.00
Volume of 1.00 mol dm^{-3} NH_3(aq) / cm^3	3.00	6.00	9.00	12.00	15.00	18.00
Volume of H_2O(l) / cm^3	17.00	14.00	11.00	8.00	5.00	2.00
Absorbance	0.25	0.50	0.76	0.84	0.84	0.84

(a) Plot a graph of absorbance against volume of NH_3(aq) on the grid opposite.

Draw a straight line of best fit through the first three points and another straight line of best fit through the last three points. Extend both lines so that they cross.

(2)

(b) (i) Use the graph to determine the smallest volume of 1.00 mol dm^{-3} NH_3(aq) required to completely react with 5.00 cm^3 of 0.500 mol dm^{-3} of $CuSO_4$ solution.

(1)

(ii) Calculate the amount, in moles, of $CuSO_4$ in 5.00 cm^3 of 0.500 mol dm^{-3} solution.

(1)

(iii) Calculate the amount of NH_3, in moles, present in the volume of NH_3(aq) in (b)(ii).

(1)

(iv) Deduce the values of x and y in the formula of the complex ion $[Cu(NH_3)_x(H_2O)_y]^{2+}$.

(1)

x = ... y = ...

(c) The precipitate formed when some of the mixtures are made is copper(II) hydroxide.

Write an ionic equation to show the formation of copper(II) hydroxide from its ions. Include state symbols.

(2)

(Total for Question 4 = 8 marks)

5 Chlorine and bromine are elements in Group 7 of the Periodic Table.

Both elements exist in a number of different oxidation numbers and therefore are involved in many redox reactions.

(a) Write an equation for the reaction between chlorine and cold, dilute aqueous sodium hydroxide. State symbols are not required.

(1)

(b) Chlorine dioxide reacts with cold, dilute aqueous sodium hydroxide.

The ionic equation for the reaction is:

$$2ClO_2(aq) + 2OH^-(aq) \rightarrow ClO_2^-(aq) + ClO_3^-(aq) + H_2O(l)$$

Using oxidation numbers, explain why the chlorine in ClO_2 has undergone disproportionation.

(3)

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(c) Chloride ions (Cl^-) can be oxidised to chlorine molecules (Cl_2) by manganate(VII) ions.

A dilute solution containing manganate(VII) ions (MnO_4^-) and an excess of dilute sulfuric acid is added to the solution containing chloride ions.

As the manganate(VII) ion solution is added, it changes from purple to colourless.

(i) The formula of the manganese species that is formed during this reaction is

(1)

☒ **A** Mn^{2+}(aq)

☒ **B** Mn^{3+}(aq)

☒ **C** Mn^{4+}(aq)

☒ **D** MnO_4^{2-} (aq)

(ii) Using oxidation numbers, deduce the molar ratio of MnO_4^- to Cl^- that would appear in the balanced chemical equation for the reaction.

(2)

(d) Potassium bromide reacts with concentrated sulfuric acid. Three of the products of the reaction are hydrogen bromide, bromine and sulfur dioxide.

(i) Explain why the hydrogen bromide, which is a colourless gas, appears as misty fumes when it makes contact with moist air.

(2)

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(ii) State the type of reaction that occurs in the formation of sulfur dioxide.

(1)

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(Total for Question 5 = 10 marks)

6 Sodium can form three oxides:

sodium oxide, Na_2O
sodium peroxide, Na_2O_2
sodium superoxide, NaO_2

It has been suggested that sodium superoxide could be used in spacecraft to regenerate oxygen.

Oxygen needs to be replaced in a spacecraft because an astronaut oxidises glucose, according to the equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Sodium superoxide can regenerate oxygen according to the equation:

$$4NaO_2 + 2CO_2 \rightarrow 2Na_2CO_3 + 3O_2$$

In order to maintain the correct percentage of oxygen in the air, any excess carbon dioxide could be removed by using sodium oxide.

$$Na_2O + CO_2 \rightarrow Na_2CO_3$$

(a) Calculate the mass of sodium oxide that would be required to remove the excess carbon dioxide when exactly 880 g of sodium superoxide is reacted per day.

You can assume that an astronaut oxidises 2 mol of glucose each day.

(4)

(b) Using a dot-and-cross diagram, explain why the superoxide ion, $O—O^-$, is a radical.

(2)

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(c) A 0.403 g sample of sodium peroxide was reacted with water:

$$Na_2O_2 + 2H_2O \rightarrow 2NaOH + H_2O_2$$

The hydrogen peroxide produced was determined by titration with a solution containing cerium(IV) ions. In this reaction the hydrogen peroxide is converted into oxygen.

$$H_2O_2 \rightarrow 2H^+ + O_2 + 2e^-$$

The hydrogen peroxide solution reacted with exactly 24.85 cm^3 of a 0.420 mol dm^{-3} solution of cerium(IV) ions, Ce^{4+}.

Deduce the formula of the cerium ion present in the final solution. Support your answer with a calculation.

(4)

(Total for Question 6 = 10 marks)

7 The following reversible reaction is used in industry to make methanol, CH_3OH:

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

(a) Which change would affect both the value of the equilibrium constant, K_c, and the proportion of methanol present in an equilibrium mixture of the three gases?

(1)

☒ **A** adding a catalyst

☒ **B** changing the temperature

☒ **C** increasing the concentration of carbon monoxide

☒ **D** increasing the pressure

(b) The expression for the equilibrium constant, K_c, for this reaction is

$$K_c = \frac{[CH_3OH(g)]}{[CO(g)][H_2(g)]^2}$$

0.200 mol of CO(g) and 0.400 mol of H_2(g) are mixed in a sealed container of volume 1.2 dm^3 at a temperature of 500 K and a pressure of 100 atmospheres and allowed to reach equilibrium.

The equilibrium mixture is found to contain 0.086 mol of CH_3OH(g).

(i) Calculate K_c for this reaction. Give your answer to an appropriate number of significant figures and state the units.

(5)

(ii) The equilibrium mixture of $CO(g)$, $H_2(g)$ and $CH_3OH(g)$ is heated in the same sealed container to a temperature higher than 500 K. Since the gas volume remains the same, the increased temperature results in an increase in pressure.

Explain why it is difficult to predict the effect on the yield of CH_3OH.

(3)

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(Total for Question 7 = 9 marks)

8 Acids can be classified as weak or strong acids.

(a) A mixture of concentrated sulfuric and nitric acids is used in the nitration of benzene.

The following equilibrium is set up:

$$H_2SO_4 + HNO_3 \rightleftharpoons H_2NO_3^+ + HSO_4^-$$

Which statement about this equilibrium is correct?

(1)

☒ **A** HNO_3 and $H_2NO_3^+$ are a conjugate acid-base pair

☒ **B** the nitric acid acts as an acid

☒ **C** the nitric acid acts as an oxidising agent

☒ **D** the sulfuric acid acts as a dehydrating agent

(b) Sulfuric acid ionises in two stages.

Stage 1: $H_2SO_4(aq) \rightarrow H^+(aq) + HSO_4^-(aq)$

Stage 2: $HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$

(i) Explain, with reference to the equations, why the HSO_4^- ion is classified as a weak acid.

(2)

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(ii) A 0.100 mol dm^{-3} solution of sulfuric acid has a pH of 0.97.

Calculate the concentration of hydrogen ions in this solution.

(1)

(c) Ethanoic acid, CH_3COOH, is a weak acid.

A student prepares 600 cm^3 of a buffer solution by mixing 400 cm^3 of 0.500 mol dm^{-3} ethanoic acid solution with 200 cm^3 of 0.500 mol dm^{-3} sodium ethanoate solution, CH_3COONa.

Calculate the pH of the buffer solution produced.

(K_a for ethanoic acid = 1.74×10^{-5} mol dm^{-3})

(4)

(Total for Question 8 = 8 marks)

9 Prussian Blue, $[Fe_4[Fe(CN)_6]_3]$, is a dark blue pigment used in painting and dyeing.

It was discovered around 1700 AD in the German state of Prussia.

Prussian Blue is formed when an iron(III) salt is added to a solution containing the complex ion $[Fe(CN)_6]^{4-}$.

The cyanide ion has the formula CN^-.

(a) (i) The oxidation number of Fe in the $[Fe(CN)_6]^{4-}$ ion is

(1)

☒ **A** +2

☒ **B** +3

☒ **C** +4

☒ **D** +6

(ii) Draw a diagram to show the shape of a $[Fe(CN)_6]^{4-}$ ion, using the structure CN^- to represent a cyanide ligand and showing how the cyanide ligands bond to the central iron ion.

(2)

(b) A solution containing $[Fe(CN)_6]^{3-}$ ions can be made from $[Fe(H_2O)_6]^{2+}$ ions in two steps as shown:

Step 1 $[Fe(H_2O)_6]^{2+}(aq) + 6CN^-(aq) \rightleftharpoons [Fe(CN)_6]^{4-}(aq) + 6H_2O(l)$

Step 2 $2[Fe(CN)_6]^{4-}(aq) + Cl_2(aq) \rightarrow 2[Fe(CN)_6]^{3-}(aq) + 2Cl^-(aq)$

Name the type of reaction taking place in each of Steps 1 and 2.

(2)

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(c) In a separate reaction, aqueous sodium hydroxide was added to a solution containing iron(II) sulfate. A green precipitate formed that turned brown on standing in air.

Identify the green precipitate and explain why it turns brown on standing in air.

(3)

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(Total for Question 9 = 8 marks)

10 This question is about some Group 2 compounds.

(a) Explain the trend in the thermal stability of carbonates in Group 2.

(3)

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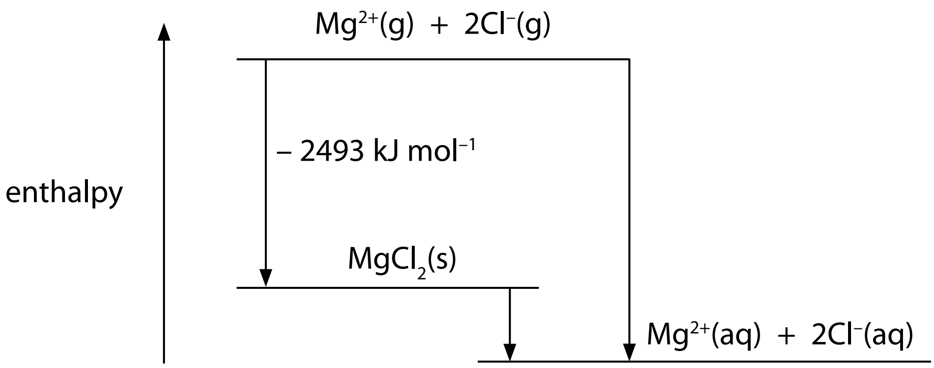
(b) Magnesium chloride is soluble in water. The enthalpy level diagram for the dissolving of magnesium chloride is



The enthalpy changes of hydration of the ions are:

Mg^{2+} −1920 kJ mol^{-1}

Cl^{-} −364 kJ mol^{-1}

Calculate the enthalpy change of solution, $\Delta H_{solution}$, of $MgCl_2$(s) in kJ mol^{-1}.

(2)

(c) The table shows some data relating to the dissolving of magnesium sulfate, $MgSO_4$, in water at 298 K.

$\Delta H^{\ominus}_{solution}$ / kJ mol^{-1}	$\Delta S^{\ominus}_{system}$ / J K^{-1} mol^{-1}
−87	−210

(i) Explain why the dissolving of magnesium sulfate in water is exothermic by considering the enthalpy changes involved.

(2)

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(ii) Use the data in the table to calculate $\Delta G^{\ominus}$ when magnesium sulfate dissolves in water at 298 K. State the significance of your answer.

(2)

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*(d) The table shows some data relating to the dissolving of barium sulfate and calcium sulfate in water at 298 K.

Salt	**$\Delta H^{\ominus}_{solution}$ / kJ mol^{-1}**	**$T\Delta S^{\ominus}_{system}$ / kJ mol^{-1}**
$BaSO_4$	+19	−31
$CaSO_4$	−18	−43

Comment on the relative solubility in water of barium sulfate and calcium sulfate at 298 K, using data from the table.

(6)

(Total for Question 10 = 15 marks)

TOTAL FOR PAPER = 90 MARKS

The Periodic Table of Elements

Key

relative atomic mass **atomic symbol** name atomic (proton) number

1	2											3	4	5	6	7	0 (8)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
							1.0 **H** hydrogen 1										4.0 **He** helium 2
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12											27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	95.9 **Mo** molybdenum 42	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La*** lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 **Ce** cerium 58	141 **Pr** praseodymium 59	144 **Nd** neodymium 60	[147] **Pm** promethium 61	150 **Sm** samarium 62	152 **Eu** europium 63	157 **Gd** gadolinium 64	159 **Tb** terbium 65	163 **Dy** dysprosium 66	165 **Ho** holmium 67	167 **Er** erbium 68	169 **Tm** thulium 69	173 **Yb** ytterbium 70	175 **Lu** lutetium 71
* Actinide series	232 **Th** thorium 90	[231] **Pa** protactinium 91	238 **U** uranium 92	[237] **Np** neptunium 93	[242] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[245] **Bk** berkelium 97	[251] **Cf** californium 98	[254] **Es** einsteinium 99	[253] **Fm** fermium 100	[256] **Md** mendelevium 101	[254] **No** nobelium 102	[257] **Lr** lawrencium 103