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

Tuesday 5 June 2018 – Afternoon
Time: 1 hour 45 minutes

Paper Reference **9CH0/01**

Candidates must have: Data Booklet
Scientific calculator

Total Marks

Instructions

- Use **black** ink or **black** 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.*
- For the question marked with an **asterisk** (*), 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.
- Check your answers if you have time at the end.
- Show all your working in calculations and include units where appropriate.

Turn over

5/5/5/5/2/1/2/

Pearson

Answer ALL questions.

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 An inorganic salt **A** contains one cation and one anion.
The results of two tests on salt **A** are shown in the table.

Test	Observation
Add aqueous sodium hydroxide to solid **A**. Warm the mixture. Test any gas evolved with damp red litmus paper.	A gas was evolved. The gas turned red litmus paper blue.
Add dilute nitric acid followed by aqueous silver nitrate to an aqueous solution of **A**.	A cream precipitate formed.

(a) Deduce the **name** of salt **A**.

(2)

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(b) Describe additional tests, with the results, that will confirm the identity of the **anion** in the cream precipitate.

(2)

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(Total for Question 1 = 4 marks)

2 This question is about atoms, molecules and ions.

(a) Lithium exists as two isotopes.

Complete the table to show the numbers of subatomic particles in a ^{6}Li **atom** and a $^{7}Li^{+}$ **ion**.

(2)

Particle	Protons	Neutrons	Electrons
^{6}Li			
$^{7}Li^{+}$			

(b) The mass spectrum of a diatomic molecule, X_2, has peaks at the following *m* / *z* values for the X_2^{+} ion:

32, 33, 34, 35, 36

Deduce the formulae of all the species responsible for **each** of the peaks in the mass spectrum of X_2, identifying element X and showing clearly the isotopes present.

(3)

(c) Complete the table to show the maximum number of electrons which can fill each region of an atom.

(3)

Region	Maximum number of electrons
the 1s orbital	
the 2p subshell	
the third quantum shell	

(Total for Question 2 = 8 marks)

3 Nitric acid reacts with sodium hydroxide solution in a neutralisation reaction.

$$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$$

In an experiment to determine the enthalpy change of neutralisation, the following results were obtained.

Volume of 1.00 mol dm^{-3} HNO_3 = 25.0 cm^3

Volume of 1.05 mol dm^{-3} NaOH = 25.0 cm^3

Temperature rise = 6.8 °C

(a) Give a reason why excess sodium hydroxide was used.

(1)

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(b) Calculate the enthalpy change of neutralisation for the reaction between nitric acid and sodium hydroxide solution, using the results of the experiment.

Give your answer to an appropriate number of significant figures.

[Assume: density of the reaction mixture = $1.0\,g\,cm^{-3}$
specific heat capacity of the reaction mixture = $4.18\,J\,g^{-1}\,°C^{-1}$]

(4)

(Total for Question 3 = 5 marks)

4 This question is about transition metals.

(a) Which of these ions has the electronic configuration $[Ar]3d^5$?

(1)

☒ **A** Cr^{3+}

☒ **B** Fe^{2+}

☒ **C** Mn^{2+}

☒ **D** Mn^{3+}

(b) In which of these complex ions does the transition metal have the oxidation number +3?

(1)

☒ **A** $[Ag(CN)_2]^-$

☒ **B** $[CuCl_4]^{2-}$

☒ **C** $[Fe(CN)_6]^{3-}$

☒ **D** $[Ni(EDTA)]^{2-}$

(c) Which type or types of bonding exist **within** the complex ion $[Cr(H_2O)_6]^{3+}$?

(1)

☒ **A** dative covalent only

☒ **B** dative covalent and covalent only

☒ **C** dative covalent and ionic only

☒ **D** dative covalent, covalent and ionic

(d) Which **best** explains why $[Cu(NH_3)_2]^+$ ions are colourless?

(1)

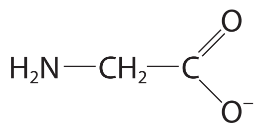
☒ **A** all complex ions having a metal ion with a +1 charge are colourless

☒ **B** no electronic transitions can take place between *d*-orbitals

☒ **C** the *d*-orbitals cannot split in energy

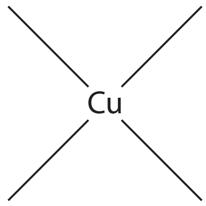
☒ **D** there are no electrons in the *d*-subshell

(e) Glycinate ions are bidentate ligands and can be represented by the structure



Complete the diagram below to show the structure of the $[Cu(NH_2CH_2COO)_2]$ complex, which is square planar.

(2)



(f) Manganate(VII) ions, MnO_4^-, react with ethanedioate ions in acid solution.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

The reaction starts slowly, the rate of reaction then increases, before it decreases again. Explain this sequence.

(3)

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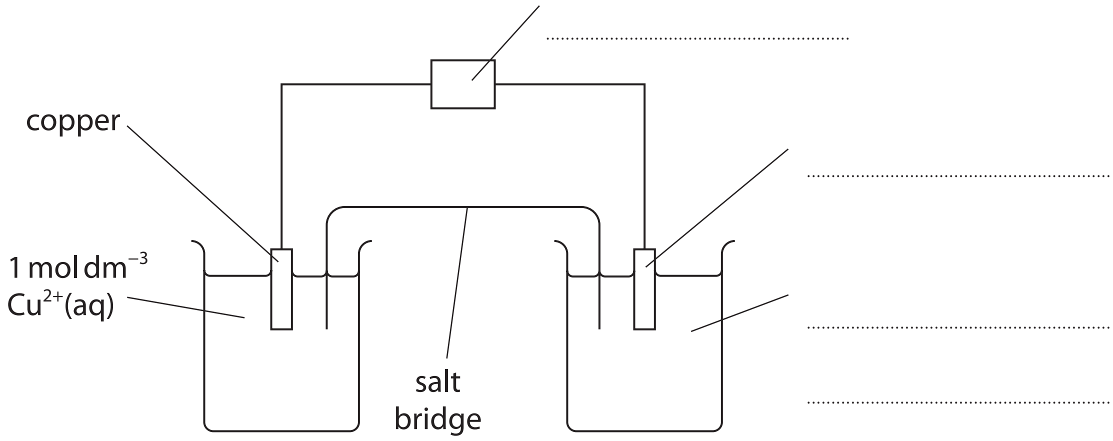
(Total for Question 4 = 9 marks)

5 An electrochemical cell is made from the electrode systems represented by these half-equations.

$$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$$

$$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$$

The $E^{\ominus}_{cell}$ value is measured using the apparatus shown.



(a) Complete the diagram by adding labels on the dotted lines provided. **(3)**

(b) A salt bridge is used to connect the two half-cells.

(i) State what chemical is contained in the salt bridge. **(1)**

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(ii) Give a possible reason why the salt bridge cannot be replaced by an unreactive metal wire. **(1)**

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(c) In this cell, the copper is oxidised and $E^{\ominus}_{cell} = +1.15\,V$.

$$Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s) \qquad E^{\ominus} = +0.34\,V$$

$$Mn^{3+}(aq) + e^{-} \rightleftharpoons Mn^{2+}(aq)$$

(i) Write the overall ionic equation for the reaction taking place.
State symbols are not required.

(1)

(ii) Calculate the value of the standard electrode potential for the $Mn^{3+}(aq)$ I $Mn^{2+}(aq)$ half-cell.

(1)

(Total for Question 5 = 7 marks)

6 This question is about the solubility of metal hydroxides.

(a) Which of these metal hydroxides is the most soluble in water?

(1)

☒ **A** barium hydroxide

☒ **B** calcium hydroxide

☒ **C** magnesium hydroxide

☒ **D** potassium hydroxide

(b) When excess magnesium hydroxide is added to water and shaken, a saturated solution is formed and the mixture reaches equilibrium.

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$$

The equilibrium constant, K_c, for this reaction is

$$K_c = [Mg^{2+}(aq)][OH^-(aq)]^2$$

(i) Give a reason why the magnesium hydroxide is not included in the expression for K_c.

(1)

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....

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....

(ii) Give the units for K_c.

(1)

(iii) Calculate the enthalpy change of solution of magnesium hydroxide, using the following data.

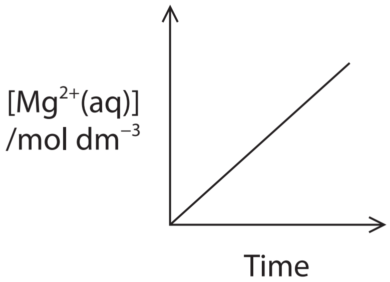
Energy or enthalpy change	Value / kJ mol^{-1}
Lattice energy of $Mg(OH)_2(s)$	−2842
$\Delta_{hyd}H$ ($Mg^{2+}(aq)$)	−1920
$\Delta_{hyd}H$ ($OH^{-}(aq)$)	−460

(2)

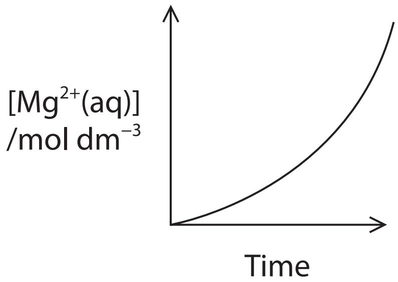
(iv) Which graph shows the change in the concentration of the $Mg^{2+}(aq)$ ions when some solid magnesium hydroxide is shaken with water and left to reach equilibrium?

(1)

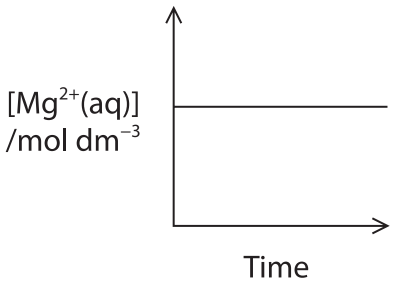
☒ **A**



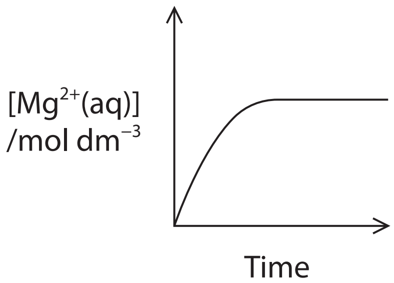
☒ **B**



☒ **C**



☒ **D**



(v) Predict the effect, if any, of adding each of the following to a saturated solution of magnesium hydroxide in contact with solid magnesium hydroxide. Justify your answers in terms of the effect on the equilibrium.

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$$

(4)

Magnesium sulfate solution

Dilute hydrochloric acid

(Total for Question 6 = 10 marks)

7 Boric acid, H_3BO_3, is a weak acid with antiseptic properties.

(a) Boric acid can be prepared by reacting borax, $Na_2B_4O_7.10H_2O$, with hydrochloric acid.

Write the equation for this reaction. State symbols are not required.

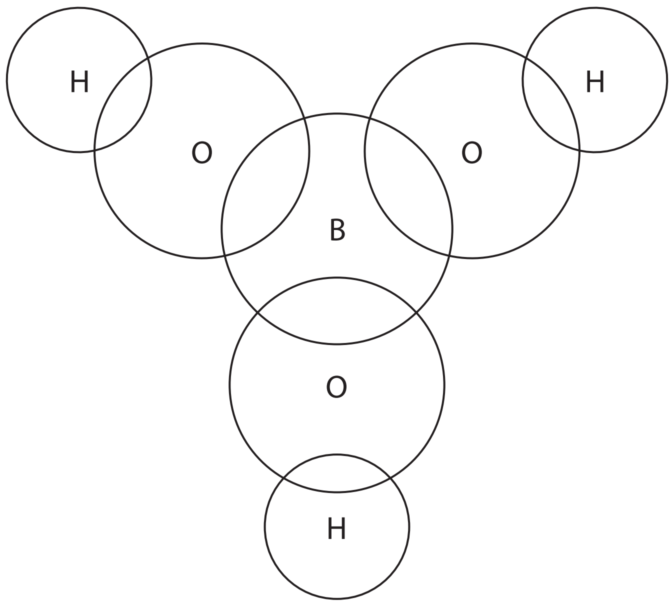
(1)

(b) The formula of boric acid can also be written as $B(OH)_3$.

(i) Complete the dot-and-cross diagram of a molecule of boric acid. Show the outer shell electrons only.

Use dots (•) for the hydrogen electrons, crosses (×) for the oxygen electrons and triangles (△) for the boron electrons.

(2)



(ii) What are the O—B—O and B—O—H bond angles in a molecule of boric acid?

(1)

	O—B—O bond angle	B—O—H bond angle
☒ **A**	109.5°	104.5°
☒ **B**	109.5°	180°
☒ **C**	120°	104.5°
☒ **D**	120°	180°

(c) Boric acid is a solid with melting temperature 171 °C.

What are the strongest interactions between the molecules in solid boric acid?

(1)

☒ **A** covalent bonds

☒ **B** hydrogen bonds

☒ **C** ionic bonds

☒ **D** London forces

(d) In aqueous solution, boric acid dissociates into ions in three stages.
The equation for the first dissociation is

$$H_3BO_3(aq) \rightleftharpoons H^+(aq) + H_2BO_3^-(aq)$$

pK_a for this dissociation is 9.24

(i) Calculate the pH of a 0.0500 mol dm^{-3} solution of boric acid from the pK_a value for the first dissociation.

(3)

(ii) State any assumptions you made in your calculation in (d)(i).

(2)

(e) Boric acid can undergo further dissociation.

Which is the conjugate acid of the HBO_3^{2-} ion?

(1)

- ☒ **A** BO_3^{3-}
- ☒ **B** $H_2BO_3^-$
- ☒ **C** H_3BO_3
- ☒ **D** H_3O^+

(Total for Question 7 = 11 marks)

8 This question is about ions and ionic compounds.

(a) The first three ionisation energies of calcium are shown in the table.

	First ionisation	Second ionisation	Third ionisation
Ionisation energy / $kJ\,mol^{-1}$	590	1145	4912
Orbital			

(i) Complete the table by identifying the specific orbital from which each electron is removed.

(2)

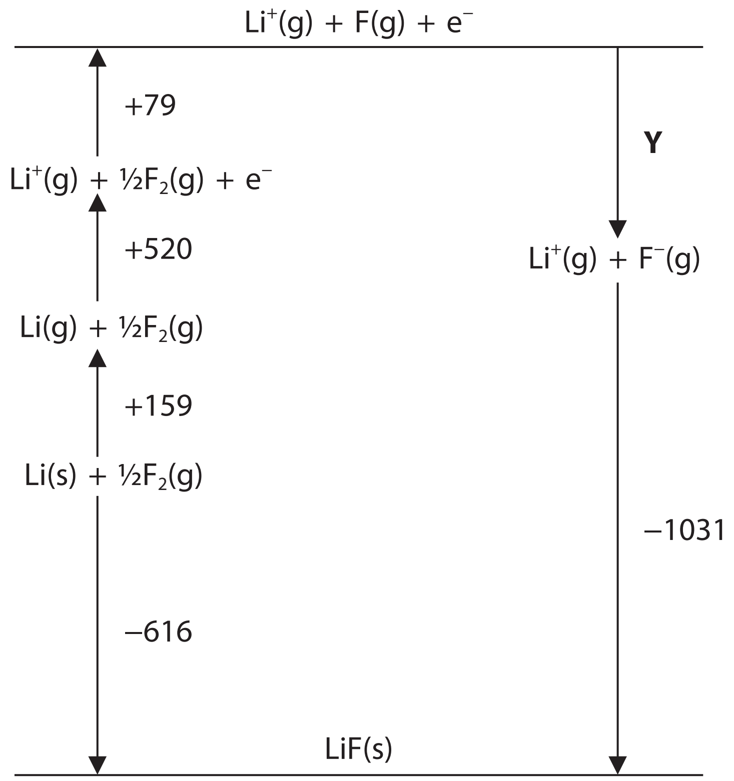
(ii) Write the equation for the **third** ionisation energy of calcium. Include state symbols.

(1)

(iii) Explain why the difference between the second and third ionisation energies of calcium is much larger than the difference between the first and second ionisation energies.

(2)

(b) The diagram, which is not drawn to scale, shows the Born-Haber cycle for lithium fluoride. The energy changes are given in $kJ\,mol^{-1}$.



What is the value for **Y**, in $kJ\,mol^{-1}$?

(1)

☒ **A** −273

☒ **B** −343

☒ **C** −432

☒ **D** −889

*(c) The table shows the theoretical and experimental lattice energy values of two compounds.

Compound	Theoretical lattice energy / $kJ\,mol^{-1}$	Experimental lattice energy / $kJ\,mol^{-1}$
lithium chloride, LiCl	−845	−848
magnesium iodide, MgI_2	−1944	−2327

Comment on the theoretical and experimental lattice energy values, giving the reasons for any differences and similarities.

(6)

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(Total for Question 8 = 12 marks)

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9 This question is about entropy and free energy.

(a) Complete the table by giving the sign of the entropy change of the system, ΔS_{system}, for each reaction.

(2)

Reaction	Sign of ΔS_{system}
$CO_2(s) \rightarrow CO_2(g)$	
$NaCl(s) + aq \rightarrow NaCl(aq)$	
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$	

(b) Calculate the total entropy change, ΔS_{total}, for the thermal decomposition of calcium carbonate at 298 K.

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

[Data: $\Delta_r H = +178\ \text{kJ mol}^{-1}$ $\Delta S_{system} = +160\ \text{J K}^{-1}\ \text{mol}^{-1}$]

(3)

(c) Sulfur dioxide reacts with oxygen to form sulfur trioxide.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta_r H = -288.4\,kJ\,mol^{-1}$$

The standard molar entropy values at 298 K are given in the table.

	$SO_2(g)$	$O_2(g)$	$SO_3(g)$
$S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$	+248.1	+205.0	+95.6

(i) Calculate the entropy change of the system, ΔS_{system}, for the forward reaction. Include a sign and units in your answer.

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

(2)

(ii) Calculate the free energy change, ΔG, at 298 K and hence deduce whether the reaction is feasible.

(3)

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(iii) In industry, the reaction is carried out at about 700 K using a vanadium(V) oxide catalyst.

Calculate the value of the equilibrium constant, K, at 700 K.

ΔG at 700 K is $-60\ \text{kJ mol}^{-1}$

(3)

(iv) The equilibrium constant has a larger value at 298 K than at 700 K. Explain why the reaction is carried out at 700 K and not at 298 K.

(2)

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(Total for Question 9 = 15 marks)

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10 Yellow gold is used to make jewellery. It is an alloy of copper, gold and silver. The purity of gold is measured in carats. The higher the carat, the higher the percentage of gold in the alloy. Pure gold is 24 carat.

A sample of yellow gold is analysed using the steps below.

Step **1** Excess concentrated nitric acid is reacted with 1.250 g of the alloy. The gold does **not** react but the copper and silver do react. The half-equations are

$$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$$

$$Ag(s) \rightarrow Ag^+(aq) + e^-$$

$$2HNO_3(aq) + e^- \rightarrow NO_3^-(aq) + NO_2(g) + H_2O(l)$$

Step **2** The mixture is diluted with distilled water and the gold is filtered off.

Step **3** Excess hydrochloric acid is added to the filtrate. It reacts with the silver ions to form a precipitate of silver chloride.

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

Step **4** The silver chloride precipitate is filtered off, washed, dried and weighed. The mass of silver chloride formed is 0.706 g.

Step **5** Excess potassium iodide is added to the remaining solution. A precipitate of copper(I) iodide and a solution of iodine forms.

$$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(aq)$$

Step **6** The resulting mixture is titrated with 0.100 mol dm^{-3} sodium thiosulfate solution.

$$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

The titre is 39.40 cm^3.

(a) Write the equation for the reaction of copper with concentrated nitric acid, using the half-equations given in Step **1**. State symbols are not required.

(1)

(b) State the indicator used and its colour change at the end-point in the titration in Step **6**.

(2)

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(c) The table shows the percentage by mass of gold in four different carats of yellow gold.

Carat	Percentage by mass of gold
9	37.5
10	41.7
14	58.3
18	75.0

Determine, using the experimental data, the carat of the sample of yellow gold that was analysed.

(6)

(Total for Question 10 = 9 marks)

TOTAL FOR PAPER = 90 MARKS

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The Periodic Table of Elements

1.0
H
hydrogen
1

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

1	2											3	4	5	6	7	0 (8)
(1)	(2)											(13)	(14)	(15)	(16)	(17)	(18)
																	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	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(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