Rewarding Learning

ADVANCED
General Certificate of Education
2024

Centre Number

Candidate Number

Chemistry

Assessment Unit A2 1
assessing
Further Physical and
Organic Chemistry

ACH14

[ACH14]
TUESDAY 28 MAY, MORNING

TIME

2 hours.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.
Answer **all sixteen** questions in **Sections A and B**.
You must answer the questions in the spaces provided.
Do not write outside the boxed area on each page or on blank pages.
Complete in black ink only. **Do not write with a gel pen or a pencil.**

INFORMATION FOR CANDIDATES

The total mark for this paper is 110.
Quality of written communication will be assessed in Questions **14(a)** and **16(c)(iii)**.
The figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.
A Periodic Table of Elements, containing some data, is included with this question paper.

Section A

For each of the following questions, only **one** of the lettered responses (A–D) is correct.

Select the correct response for each question and write the appropriate letter in the space provided.

1 Which one of the following compounds does **not** react with nucleophiles?

A CH_3CH_2CHO

B CH_3CHCH_2

C $CH_3CH_2COCH_3$

D $CH_3CH_2CH_2Cl$

Answer _____ [1]

2 In which one of the following reaction mixtures does a redox reaction occur?

A ethanal and hydrogen cyanide

B ethanal and Tollens' reagent

C ethanoic acid and sodium hydroxide

D ethanoyl chloride and ethanol

Answer _____ [1]

3 The boiling point of ethyl ethanoate is 77 °C. The boiling point of pentyl hexanoate is 226 °C. Which one of the following is responsible for the higher boiling point of pentyl hexanoate?

A covalent bonds

B hydrogen bonds

C permanent dipole-dipole attractions

D van der Waals' forces

Answer _____ [1]

4 Propanone reacts with 2,4-dinitrophenylhydrazine to form a 2,4-dinitrophenylhydrazone. Which one of the following is the molecular formula of the 2,4-dinitrophenylhydrazone?

A $C_9H_8N_4O_4$

B $C_9H_{10}N_3O_4$

C $C_9H_{10}N_4O_4$

D $C_9H_{11}N_4O_4$

Answer _____ [1]

5 Which one of the following is correct for the entropy change and enthalpy change for a reaction which is feasible at all temperatures?

	ΔS	**ΔH**
A	negative	negative
B	negative	positive
C	positive	negative
D	positive	positive

Answer _____ [1]

[Turn over

6 Which one of the following statements is **not** correct?

A a benzene molecule contains 24 electrons

B all carbon–carbon bonds in benzene are the same length

C benzene undergoes substitution reactions

D chlorine reacts more slowly with benzene than it does with ethene

Answer _____ [1]

7 A pure sample of a fat is known to be the triester of glycerol and a fatty acid. 0.30 mol of the fat requires 21.6 dm^3 of hydrogen at room temperature for complete hydrogenation. Which one of the following is the formula of the fatty acid in the fat?

A $C_{15}H_{31}COOH$

B $C_{17}H_{31}COOH$

C $C_{17}H_{33}COOH$

D $C_{17}H_{35}COOH$

Answer _____ [1]

8 Propanone can be reduced to form an alcohol. Which one of the following is an isomer of the alcohol formed, which belongs to a different homologous series?

A $CH_3CH_2CH_2OH$

B CH_3CH_2CHO

C $CH_3OCH_2CH_3$

D $CH_3CH(OH)CH_3$

Answer _____ [1]

9 Which one of the following does **not** contain an asymmetric centre?

A $CH_3CH(CH_3)CH_2CH_3$

B $CH_3CH(OH)CH_2CH_3$

C $CH_3CHClCH_2CH_3$

D $CH_3CH(NH_2)CH_2CH_3$

Answer _____ [1]

10 The rate of decomposition of ethanal at 500 °C is given by the equation:

$$\text{rate} = k\,[\text{ethanal}]^2$$

Which one of the following shows the units for k?

A s^{-1}

B $mol\ dm^{-3}\ s^{-1}$

C $mol^{-1}\ dm^3\ s^{-1}$

D $mol^{-2}\ dm^6\ s^{-1}$

Answer _____ [1]

[Turn over

Section B

Answer **all six** questions in this section

11 A cleaning solution is a solution of sodium hydroxide.

(a) A sample of 25.0 cm^3 of the cleaning solution was titrated using 0.525 mol dm^{-3} ethanoic acid. The mean titre was found to be 17.2 cm^3.

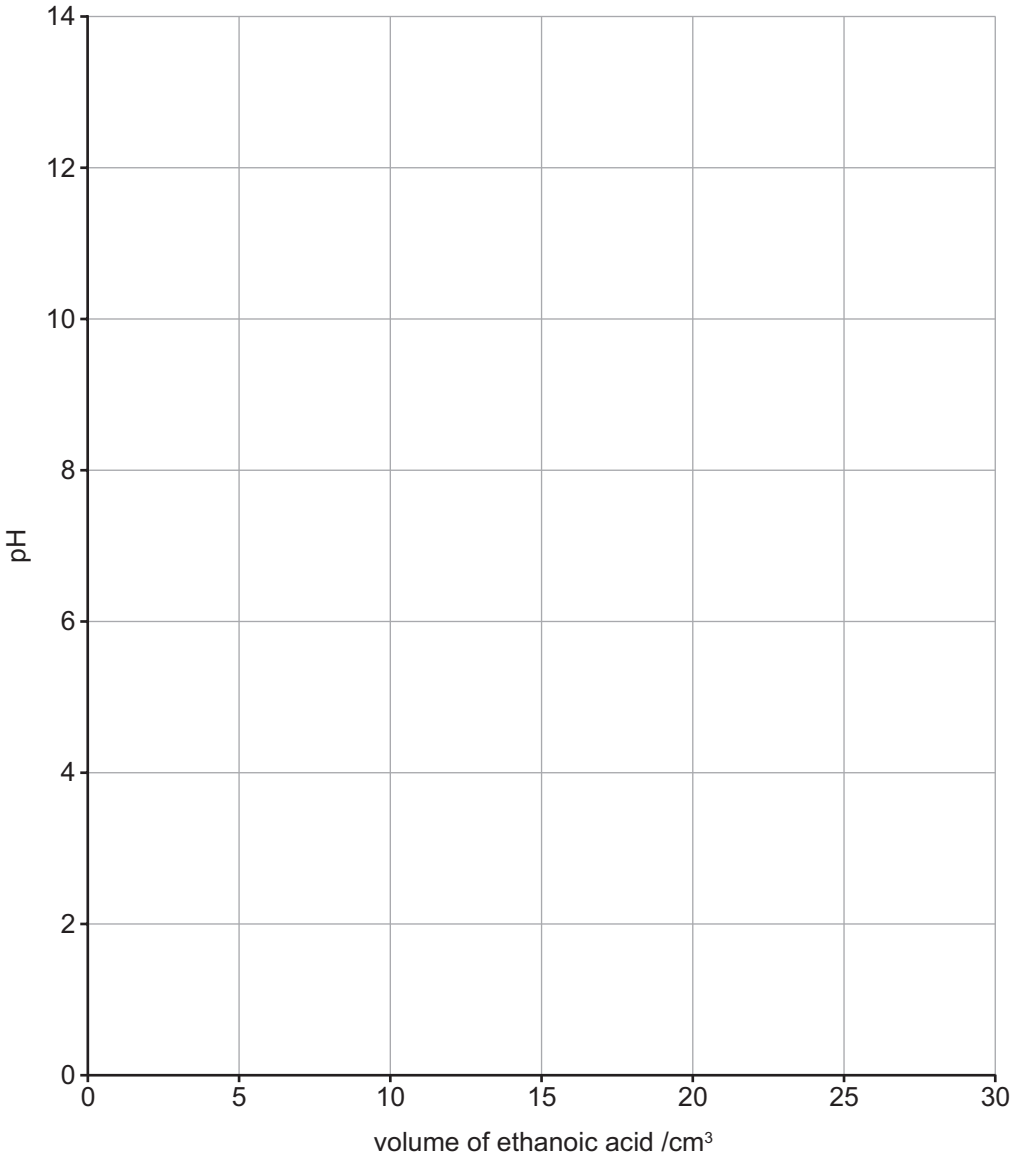
(i) Calculate the concentration, in mol dm^{-3}, of sodium hydroxide in the cleaning solution. Give your answer to 3 significant figures.

Answer _____ mol dm^{-3} [2]

(ii) Calculate the pH of the cleaning solution at 25 °C. Give your answer to 2 decimal places.
$K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6} at 25 °C.

Answer _____ [2]

(iii) Using your answer to **(a)(ii)** and the information given in the question, sketch the titration curve for this titration on the axes below.



[3]

(iv) Name an indicator for this titration and explain why it is a suitable choice.

_____

_____

_____

_____ [2]

[Turn over

(b) 25.0 cm^3 of the cleaning solution may also be titrated using 0.525 mol dm^{-3} sulfuric acid.

(i) Describe two ways in which the titration curve would be different to the one in **(a)(iii)**.

1. _____

_____

2. _____

_____ [2]

(ii) 20.0 cm^3 of the 0.525 mol dm^{-3} sulfuric acid were placed in a volumetric flask and the volume made up to 250.0 cm^3 using deionised water. Calculate the pH of the resulting solution. Give your answer to 2 decimal places.

Answer _____ [3]

(c) Sodium hydroxide reacts with phosphoric acid, H_3PO_4, to form salts including sodium hydrogenphosphate, Na_2HPO_4. The hydrogenphosphate ion can act as a Brønsted–Lowry acid and as a Brønsted–Lowry base.

(i) Write an equation for the reaction between sodium hydroxide and phosphoric acid to form sodium hydrogenphosphate.

_____ [1]

(ii) Show, using equations, how the hydrogenphosphate ion can act as a Brønsted–Lowry acid and as a Brønsted–Lowry base in aqueous solution.

_____

_____ [2]

(iii) Another salt of phosphoric acid is sodium phosphate, Na_3PO_4. Explain why a solution of sodium phosphate is alkaline.

_____

_____

_____ [1]

[Turn over

12 Butanoic acid and 2-hydroxypropanoic acid are weak monobasic acids. The table below summarises some properties of both acids.

Acid	Formula	Boiling point /°C	Acid dissociation constant (K_a) at 25 °C /mol dm^{-3}
butanoic acid	$CH_3CH_2CH_2COOH$	163.5	1.51×10^{-5}
2-hydroxypropanoic acid	$CH_3CH(OH)COOH$	122.0	1.38×10^{-4}

(a) (i) Define the term **monobasic acid**.

_____

_____ [1]

(ii) Suggest why the boiling point of butanoic acid is higher than the boiling point of 2-hydroxypropanoic acid.

_____

_____

_____ [2]

(iii) On mixing 2-hydroxypropanoic acid with butanoic acid, an acid-base equilibrium is set up. Give the formula for the base and its conjugate acid for the forward reaction in this equilibrium.

base: _____

conjugate acid: _____ [2]

(iv) Calculate the mass of 2-hydroxypropanoic acid required to produce a 250.0 cm^3 solution with a pH of 2.40. Give your answer to 3 significant figures.

Answer _____ g [4]

[Turn over

(b) 2-hydroxypropanoic acid, $CH_3CH(OH)COOH$, is also known as lactic acid. Industrially, lactic acid is produced by the addition of hydrogen cyanide to ethanal to form a hydroxynitrile followed by hydrolysis of the hydroxynitrile.

(i) Write the equation for the reaction of ethanal with hydrogen cyanide to form the hydroxynitrile.

_____ [1]

(ii) Suggest the IUPAC name for the hydroxynitrile formed in the reaction of ethanal and hydrogen cyanide.

_____ [1]

(iii) Name the mechanism for the reaction of ethanal with hydrogen cyanide.

_____ [1]

(iv) Draw the three-dimensional structures for the two optical isomers of the hydroxynitrile formed in **(b)(i)**.

[2]

(v) Define the term **optical isomers**.

_____

_____

_____ [1]

(vi) Write the equation for the acid hydrolysis of the hydroxynitrile formed in **(b)(i)** to produce lactic acid.

_____ [2]

(vii) State why the lactic acid produced is not optically active.

_____

_____ [1]

[Turn over

13 Ethanoic acid and ethane-1,2-diol react together to form the diester $C_6H_{10}O_4$.

$$2CH_3COOH + HOCH_2CH_2OH \rightleftharpoons C_6H_{10}O_4 + 2H_2O$$

(a) Draw the structure for the diester $C_6H_{10}O_4$.

[1]

(b) A mixture of 0.550 moles of ethanoic acid and 0.205 moles of ethane-1,2-diol was allowed to reach equilibrium.

Substance	**CH_3COOH**	**$HOCH_2CH_2OH$**	**$C_6H_{10}O_4$**	**H_2O**
Initial amount in mixture /mol	0.550	0.205	0	0
Equilibrium amount in mixture /mol	0.260			

(i) Complete the table above. [3]

(ii) Write an expression for the equilibrium constant, K_c, for this reaction.

_____ [1]

(iii) Explain why the total volume of the mixture is not needed to calculate the value of K_c.

_____

_____

_____ [1]

(iv) Calculate the value of K_c for this equilibrium reaction.

Answer _____ [2]

[Turn over

14 (a) Propyl methanoate is a liquid ester. It can be hydrolysed in alkaline conditions as shown by the equation below.

$$HCOOCH_2CH_2CH_3 + OH^- \rightarrow HCOO^- + CH_3CH_2CH_2OH$$

Describe how you would follow the rate of this reaction with respect to hydroxide ions using pH and how you would use your results to find the order of reaction with respect to hydroxide ions.

In this question you will be assessed on your written communication skills including the use of specialist scientific terms.

[6]

(b) Some data for the hydrolysis of propyl methanoate are given below.

Experiment	$[HCOOCH_2CH_2CH_3]$ /mol dm^{-3}	$[OH^-]$ /mol dm^{-3}	Initial rate of the reaction ($\times 10^{-4}$) /mol dm^{-3} s^{-1}
1	0.040	0.030	4.00
2	0.040	0.045	6.00
3	0.060	0.045	9.00
4	0.120	0.060	to be calculated

(i) State the order of the reaction with respect to propyl methanoate.

Answer _____ [1]

(ii) State the order of the reaction with respect to hydroxide ions.

Answer _____ [1]

(iii) Calculate the initial rate of reaction for **Experiment 4**.

Answer _____ mol dm^{-3} s^{-1} [1]

(iv) State the effect, if any, of increasing the temperature on the value of the rate constant.

_____ [1]

[Turn over

(c) Fats are formed from glycerol and fatty acids. The table below shows some fatty acids.

Fatty acid	IUPAC name	Formula
A	octadecanoic acid	$CH_3(CH_2)_{16}COOH$
B	octadec-9-enoic acid	
C	octadeca-9,12-dienoic acid	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$

(i) State the IUPAC name of glycerol.

_____ [1]

(ii) Write the formula for the fatty acid **B** in **the table**.

[1]

(iii) Write the equation for the formation of a fat from one molecule of glycerol and three molecules of fatty acid **A**.

[2]

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(Questions continue overleaf)

[Turn over

15 Group I elements are highly reactive and form a variety of compounds many of which are very soluble in water.

(a) Rubidium ignites spontaneously when exposed to air to form rubidium oxide.

The following enthalpy changes can be used to calculate the standard enthalpy of formation of rubidium oxide.

Enthalpy change	Equation	ΔH /kJ mol^{-1}
A	$Rb(s) \rightarrow Rb(g)$	+86
B	$Rb(g) \rightarrow Rb^+(g) + e^-$	+402
C	$\frac{1}{2}O_2(g) \rightarrow O(g)$	+249
D	$Rb_2O(s) \rightarrow 2Rb^+(g) + O^{2-}(g)$	+2161
E	$O(g) + e^- \rightarrow O^-(g)$	–142
F	$O^-(g) + e^- \rightarrow O^{2-}(g)$	+844

(i) Write an equation for the standard enthalpy of formation of rubidium oxide.

_____ [1]

(ii) Name the enthalpy changes C, D and E in the table above.

C _____

D _____

E _____ [3]

(iii) Calculate the standard enthalpy of formation of rubidium oxide.

Answer _____ kJ mol^{-1} [2]

(b) Rubidium reacts vigorously with gaseous iodine to form the white solid, rubidium iodide.

(i) Write an equation, including state symbols, for the formation of rubidium iodide.

_____ [1]

(ii) Using the following data, calculate the enthalpy of solution of rubidium iodide.

$Rb^+(g) + I^-(g) \rightarrow RbI(s)$ $\quad -617\,kJ\,mol^{-1}$

$Rb^+(g) \rightarrow Rb^+(aq)$ $\quad -296\,kJ\,mol^{-1}$

$I^-(g) \rightarrow I^-(aq)$ $\quad -308\,kJ\,mol^{-1}$

Answer _____ kJ mol^{-1} [2]

[Turn over

(c) Sodium nitrate decomposes on heating, to form sodium nitrite and oxygen, as shown by the equation below.

$$2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$$

The minimum temperature required for this decomposition is 968 K.

The table below shows some standard enthalpy of formation data and some entropy values.

Substance	$\Delta_f H^{\ominus}$ /kJ mol^{-1}	Entropy /J K^{-1} mol^{-1}
$NaNO_3(s)$	–467	to be calculated
$NaNO_2(s)$	–359	120
$O_2(g)$	0	205

(i) What is the systematic name for sodium nitrite?

_____ [1]

(ii) Suggest why the decomposition temperature of potassium nitrate would be higher than the decomposition temperature of sodium nitrate.

_____

_____ [2]

(iii) Calculate the enthalpy change for the decomposition of sodium nitrate as shown by the equation below:

$$2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$$

Answer _____ [2]

(iv) Using the minimum temperature required for the decomposition (968 K) and your answer to **(c)(iii)**, calculate the entropy change in J K^{-1} mol^{-1} for the decomposition.

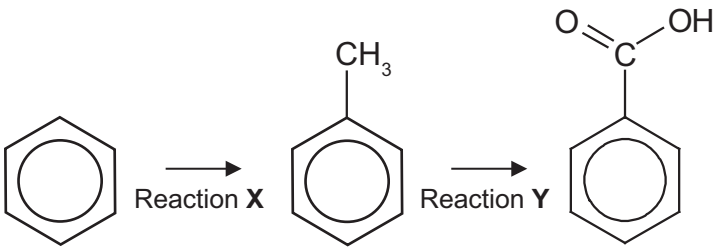
Answer _____ J K^{-1} mol^{-1} [3]

(v) Using your answer to **(c)(iv)**, calculate the entropy value for sodium nitrate.

Answer _____ J K^{-1} mol^{-1} [2]

[Turn over

16 (a) Benzoic acid is formed from benzene in a process which involves two reactions **X** and **Y**.



During Reaction **X**, benzene reacts with chloromethane in the presence of aluminium chloride. In Reaction **Y**, methylbenzene is heated with acidified potassium dichromate(VI) solution.

(i) State the function of aluminium chloride during Reaction **X**.

_____ [1]

(ii) Name the mechanism for Reaction **X**.

_____ [1]

(iii) The mechanism for Reaction **X** is shown below. Complete the mechanism.

$CH_3Cl + AlCl_3 \rightarrow \overset{+}{C}H_3 +$ _____

_____ + _____ → $AlCl_3$ + _____

[5]

(iv) Suggest the type of reaction that is taking place during Reaction **Y**.

_____ [1]

(v) Benzoic acid reacts with phosphorus pentachloride. Write an equation for this reaction.

_____ [1]

(b) Methyl benzoate, a colourless liquid ester, is formed by the reaction of benzoic acid with methanol in the presence of a catalyst. The crude methyl benzoate distillate is collected over the temperature range 197 °C to 201 °C.

(i) Name a suitable catalyst for this reaction.

_____ [1]

(ii) The crude ester is purified and a pure sample of methyl benzoate is collected at 199 °C.

Outline, in general, the three main steps carried out in the purification of the crude ester to obtain a pure sample of methyl benzoate at 199 °C.

Step 1. _____

_____

Step 2. _____

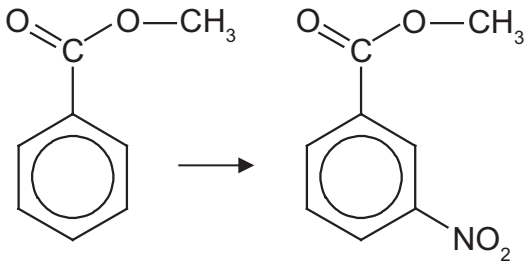
_____

Step 3. _____

_____ [3]

[Turn over

(c) Nitration of methyl benzoate produces methyl 3-nitrobenzoate. A nitrating mixture is used in this reaction.



(i) Name the two reagents which are mixed together to form the nitrating mixture.

_____

_____ [2]

(ii) The nitronium ion forms in the nitrating mixture. Write an equation for the formation of the nitronium ion.

_____ [2]

(iii) Describe, including experimental details, how you would prepare a pure, dry sample of methyl 3-nitrobenzoate from methyl benzoate and the nitrating mixture.

In this question you will be assessed on your written communication skills including the use of specialist scientific terms.

[6]

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General Information

1 tonne = 10^6 g
1 metre = 10^9 nm
One mole of any gas at 293 K and a pressure of 1 atmosphere (10^5 Pa) occupies a volume of 24 dm^3
Avogadro Constant = 6.02×10^{23} mol^{-1}
Planck Constant = 6.63×10^{-34} J s
Specific Heat Capacity of water = 4.2 J g^{-1} K^{-1}
Speed of Light = 3×10^8 m s^{-1}

Characteristic absorptions in IR spectroscopy

Wavenumber/cm^{-1}	Bond	Compound
550–850	C–X (X = Cl, Br, I)	Haloalkanes
750–1100	C–C	Alkanes, alkyl groups
1000–1300	C–O	Alcohols, esters, carboxylic acids
1450–1650	C=C	Arenes
1600–1700	C=C	Alkenes
1650–1800	C=O	Carboxylic acids, esters, aldehydes, ketones, amides, acyl chlorides
2200–2300	C≡N	Nitriles
2500–3200	O–H	Carboxylic acids
2750–2850	C–H	Aldehydes
2850–3000	C–H	Alkanes, alkyl groups, alkenes, arenes
3200–3600	O–H	Alcohols
3300–3500	N–H	Amines, amides

Proton Chemical Shifts in Nuclear Magnetic Resonance Spectroscopy (relative to TMS)

Chemical Shift	Structure	
0.5–2.0	–C**H**	Saturated alkanes
0.5–5.5	–O**H**	Alcohols
1.0–3.0	–N**H**	Amines
2.0–3.0	–CO–C**H**	Ketones
	–N–C**H**	Amines
	C_6H_5–C**H**	Arene (aliphatic on ring)
2.0–4.0	X–C**H**	X = Cl or Br (3.0–4.0)
		X = I (2.0–3.0)
4.5–6.0	–C=C**H**	Alkenes
5.5–8.5	RCON**H**	Amides
6.0–8.0	–C_6**H**$_5$	Arenes (on ring)
9.0–10.0	–C**H**O	Aldehydes
10.0–12.0	–COO**H**	Carboxylic acids

These chemical shifts are concentration and temperature dependent and may be outside the ranges indicated above.

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Data Leaflet

Including the Periodic Table of the Elements

For the use of candidates taking
Advanced Subsidiary and
Advanced Level Examinations

Copies must be free from notes or additions of any kind. No other type of data booklet or information sheet is authorised for use in the examinations

gce a/as examinations

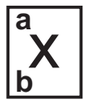
chemistry

THE PERIODIC TABLE OF ELEMENTS

I	II											III	IV	V	VI	VII	0
Group																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1																	4 He Helium 2
7 Li Lithium 3	9 Be Beryllium 4											11 B Boron 5	12 C Carbon 6	14 N Nitrogen 7	16 O Oxygen 8	19 F Fluorine 9	20 Ne Neon 10
23 Na Sodium 11	24 Mg Magnesium 12											27 Al Aluminium 13	28 Si Silicon 14	31 P Phosphorus 15	32 S Sulfur 16	35.5 Cl Chlorine 17	40 Ar Argon 18
39 K Potassium 19	40 Ca Calcium 20	45 Sc Scandium 21	48 Ti Titanium 22	51 V Vanadium 23	52 Cr Chromium 24	55 Mn Manganese 25	56 Fe Iron 26	59 Co Cobalt 27	59 Ni Nickel 28	64 Cu Copper 29	65 Zn Zinc 30	70 Ga Gallium 31	73 Ge Germanium 32	75 As Arsenic 33	79 Se Selenium 34	80 Br Bromine 35	84 Kr Krypton 36
85 Rb Rubidium 37	88 Sr Strontium 38	89 Y Yttrium 39	91 Zr Zirconium 40	93 Nb Niobium 41	96 Mo Molybdenum 42	98 Tc Technetium 43	101 Ru Ruthenium 44	103 Rh Rhodium 45	106 Pd Palladium 46	108 Ag Silver 47	112 Cd Cadmium 48	115 In Indium 49	119 Sn Tin 50	122 Sb Antimony 51	128 Te Tellurium 52	127 I Iodine 53	131 Xe Xenon 54
133 Cs Caesium 55	137 Ba Barium 56	139 La* Lanthanum 57	178 Hf Hafnium 72	181 Ta Tantalum 73	184 W Tungsten 74	186 Re Rhenium 75	190 Os Osmium 76	192 Ir Iridium 77	195 Pt Platinum 78	197 Au Gold 79	201 Hg Mercury 80	204 Tl Thallium 81	207 Pb Lead 82	209 Bi Bismuth 83	210 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	285 Cn Copernicium 112						

140 Ce Cerium 58	141 Pr Praseodymium 59	144 Nd Neodymium 60	145 Pm Promethium 61	150 Sm Samarium 62	152 Eu Europium 63	157 Gd Gadolinium 64	159 Tb Terbium 65	162 Dy Dysprosium 66	165 Ho Holmium 67	167 Er Erbium 68	169 Tm Thulium 69	173 Yb Ytterbium 70	175 Lu Lutetium 71
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

* 58 – 71 Lanthanum series
† 90 – 103 Actinium series



a = relative atomic mass (approx)
x = atomic symbol
b = atomic number

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