Isaac Chemistry Skills

Developing mastery of essential pre-university physical chemistry

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Periphyseos Press
Cambridge, UK.

PERIPHYSEOS PRESS
Cambridge

Cavendish Laboratory
J. J. Thomson Avenue, Cambridge CB3 0HE, UK

Published in the United Kingdom by Periphyseos Press, Cambridge
www.periphyseos.org.uk

First published 2016. First, second & third reprints, 2017.

Printed and bound in the UK by Short Run Press Limited, Exeter.

Typeset in LaTeX

A catalogue record for this publication is available from the British Library

ISBN 978-0-9572873-5-8 Paperback

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Contents

Notes for the Student and the Teacher

- "Developing mastery of essential pre-university physical chemistry" is associated with the **O**pen **P**latform for **A**ctive **L**earning : `isaacchemistry.org`
- The problems in this book are designed, graded and arranged by sections for understanding and mastery of the concepts and problem solving required at A-level chemistry and for equivalent exams.
- A mapping of each section of the book on to the relevant parts of all major UK chemistry exam specification is given on pages vi and vii. [With thanks to Dr David Paterson.] On-line, the mapping at `isaacchemistry.org/pages/syll_map_chem` allows 2-click setting of a chosen section as homework. See also below for teacher functionality.
- Each question can be answered on the above OPAL where there is immediate marking and some feedback. Practice to achieve *mastery* will give fluency and confidence in the essential skills required for strong A-level results and in the transition to university. Mastery level, that is achieving at least 80% of questions correct, is indicated in the marginal square boxes .

$^{n}/_{m}$

- Students should register (free) on Isaac. Go to `isaacchemistry.org` – click the "log in" tab and then "sign up" if not already registered. Physics registration on `isaacphysics.org` carries over for chemistry, and *vice versa*. A benefit of registration is that all activity is recorded for the student. Should questions be later set as homework, they will automatically be noted as done. All activity is confidential to the student, except parts that the student decides to share with a teacher (e.g. set home work).
- Teachers who register can have their Isaac accounts converted to teacher accounts (see at the foot of the user profile page). They can then set home work, and have it automatically marked with results returned to them: See "For Teachers" at `isaacchemistry.org` or go directly to `isaacchemistry.org/teacher_features`. Chemistry and physics functionalities are the same and are activated by registration on either the Physics or Chemistry sites.
- Visit `isaacchemistry.org` for physical chemistry problems in addition to these chemistry book problems (currently at "Further problem solving"). Be sure to select the level required, or otherwise get questions from all levels. These questions are all chemical thermodynamics for pre-AS, AS, A2, & the transition to university, with reaction kinetics soon to follow.
- See the physics companion book, also at `www.isaacbooks.org/`. It too is available for £1 per copy. Problems from the physics book can be answered on-line at `isaacphysics.org/physics_skills_14`.
- Maths problems to give the fluency required at chemistry and physics A-level, and equivalents, are available on `isaacphysics.org`.

Using Isaac Chemistry with this book

Isaac Chemistry offers on-line versions of each sheet at `isaacchemistry.org/book16` where a student can enter answers. This on-line tool will mark answers, giving immediate feedback to a student who, if registered on `isaacchemistry.org`, can have their progress stored and even retrieved for their CV! Teachers can set a sheet for class homework as the appropriate theme is being taught, and again for pre-exam revision. Isaac Chemistry can return the fully assembled and analysed marks to the teacher, if registered for this free service. Isaac Chemistry zealously follows the significant figures (sf) rules below and warns if your answer has a sf problem.

Uncertainty and Significant Figures

In chemistry, numbers represent values that have uncertainty and this is indicated by the number of significant figures in an answer.

Significant figures

When there is a decimal point (dp), all digits are significant, except leading (leftmost) zeros: 2.00 (3 sf); 0.020 (2 sf); 200.1 (4 sf); 200.010 (6 sf)

Numbers without a dp can have an *absolute accuracy*: 4 people; 3 electrons.

Some numbers can be ambiguous: 200 could be 1, 2 or 3 sf (see below). Assume such numbers have the same number of sf as other numbers in the question.

Combining quantities

Multiplying or dividing numbers gives a result with a number of sf equal to that of the number with the smallest number of sf:

$x = 2.31$, $y = 4.921$ gives $xy = 11.4$ (3 sf, the same as x).

An absolutely accurate number multiplied in does not influence the above.

Standard form

On-line, and sometimes in texts, one uses a letter 'x' in place of a times sign and ˆ denotes "to the power of":

1800000 could be 1.80x10ˆ6 (3 sf) and 0.0000155 is 1.55x10ˆ-5

(standardly, 1.80×10^6 and 1.55×10^{-5})

The letter 'e' can denote "times 10 to the power of": 1.80e6 and 1.55e-5.

Significant figures in standard form

Standard form eliminates ambiguity: In $n.nnn \times 10^n$, the numbers before and after the decimal point are significant:

$191 = 1.91 \times 10^2$ (3 sf); 191 is $190 = 1.9 \times 10^2$ (2 sf); 191 is $200 = 2 \times 10^2$ (1 sf).

Answers to questions

In this book and on-line, give the appropriate number of sf: For example, when the least accurate data in a question is given to 3 significant figures, then the answer should be given to three significant figures; see above. Too many sf are meaningless; giving too few discards information. Exam boards also require consistency in sf.

		OCR A (H032/H432)	OCR B (H033/H433)	AQA (7404/7405)	Edexcel (8CH0/9CH0)	Eduqas (A410QS)	CIE Pre-U (9791)	IB Chemistry (Higher)
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		OCR A (H032/H432)	OCR B (H033/H433)	AQA (7404/7405)	Edexcel (8CH0/9CH0)	Eduqas (A410QS)	CIE Pre-U (9791)	IB Chemistry (Higher)
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M5	Michaelis-Menten kinetics		(PL(f))				(B1.7)	B.7

Table of Constants

Quantity	Magnitude	Unit
Gas constant (R)	8.31	$J\ mol^{-1}\ K^{-1}$
Electron volt (eV)	1.60×10^{-19}	J
Avogadro's number (N_A)	6.02×10^{23}	–
Boltzmann's constant	1.38×10^{-23}	$J\,K^{-1}$
Speed of light (*in vacuo*)	3.00×10^{8}	$m\,s^{-1}$
Atomic mass unit (u)	1.66054×10^{-27}	kg
Planck's constant (h)	6.63×10^{-34}	J s
Charge on electron	1.60×10^{-19}	C
0 °C	273.15	K
Specific heat capacity of water	4180	$J\,kg^{-1}\,K^{-1}$
Density of water at RTP	1.00	$g\,cm^{-3}$
Faraday constant	96485	$C\,mol^{-1}$
Volume of gas at RTP	24	$dm^{3}\,mol^{-1}$
Room Temperature	298	K
Room Pressure = 1 Atm.	1.013×10^{5}	Pa

Chapter A

Formulae & Equations

The boxed fraction shows how many questions need to be answered correctly to achieve mastery.

A1 Empirical formulae

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A1.1 Find the empirical formulae for the ten compounds (a)–(j) from the data given. No compound contains more than 15 atoms in total in its formula. Show all your working in neat, clearly-presented answers. All compositions are by mass.

a) 35.0% Nitrogen, 5.0% Hydrogen, 60.0% Oxygen

b) 90.7% Lead, 9.3% Oxygen

c) 26.6% Potassium, 35.3% Chromium, 38.1% Oxygen

d) 40.3% Potassium, 26.8% Chromium, 32.9% Oxygen

e) 29.4% Vanadium, 9.2% Oxygen, 61.4% Chlorine

f) 81.8% Carbon, 18.2% Hydrogen

g) 38.7% Carbon, 9.7% Hydrogen, 51.6% Oxygen

h) 77.4% Carbon, 7.5% Hydrogen, 15.1% Nitrogen

i) 25.9% Nitrogen, 74.1% Oxygen

j) 29.7% Carbon, 5.8% Hydrogen, 26.5% Sulphur, 11.6% Nitrogen, 26.4% Oxygen

Element	Atomic mass	Element	Atomic mass
Hydrogen	1.0	Chlorine	35.5
Carbon	12.0	Potassium	39.1
Nitrogen	14.0	Vanadium	50.9
Oxygen	16.0	Chromium	52.0
Sulphur	32.1	Lead	207.2

A1.2 Complete combustion of 6.4 g of compound K produced 8.8 g of carbon dioxide and 7.2 g of water. Calculate the empirical formula of K.

A1.3 Complete combustion of 1.8 g of compound L produced 2.64 g of carbon dioxide, 1.08 g of water and 1.92 g of sulfur dioxide. Calculate the empirical formula of L.

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A2 A_r & M_r and molecular formula

Assume that the mass of an isotope in amu *to* 3 *s.f. is equal to its mass number.*

A2.1 Which isotope is used as the standard against which relative atomic masses are calculated?

A2.2 Fluorine only occurs naturally in one isotope, ^{19}F, and has a relative atomic mass of 19.0 amu. Calculate the mass of a fluorine atom in kg.

A2.3 Magnesium has the following natural isotopes: ^{24}Mg 78.6%; ^{25}Mg 10.1%; ^{26}Mg 11.3%. Calculate the relative atomic mass of magnesium.

A2.4 The relative atomic mass of boron is 10.8 amu. Boron exists in two isotopes, ^{10}B and ^{11}B. Calculate the percentage abundance of ^{10}B.

A2.5 Complete the table below:

ELEMENT	A_r	Isotope 1	Isotope 2	Isotope 3	Isotope 4
Bromine	(a)	^{79}Br 50.5%	^{81}Br 49.5%	n/a	n/a
Silver	107.9	(b) ^{107}Ag **?**%	(c) ^{109}Ag **?**%	n/a	n/a
Cerium	140.2	^{136}Ce 0.2%	^{138}Ce 0.2%	^{140}Ce 88.5%	(d) $^{\mathbf{?}}Ce$ 11.1%

A2.6 The relative molecular mass of compound M is 135 amu. M contains 3.7% hydrogen, 44.4% carbon and 51.9% nitrogen by mass. Find the molecular formula of M.

A2.7 Complete combustion of compound N occurs in a stoichiometric ratio of 1 : 6 with oxygen gas. Complete combustion of 4.2 g of compound N produces 13.2 g of carbon dioxide and 5.4 g of water. Find the molecular formula of N.

Chapter B

Amount of Substance

B1 Standard form

$^{12}/_{14}$

B1.1 Complete the following calculations, giving the answers in standard form to the appropriate number of significant figures. For guidance on this and on how to enter your answers on `isaacchemistry.org`, consult page ii of this book.

a) 120×70

b) $5600 + 800 + 12 + 1100 + 320$

c) $\dfrac{95.0}{19000}$

d) $12000 + 84000 + (3.00 \times 10^3) + 29000$

e) $(4.0 \times 10^2) \times 100 \times 300$

f) $\dfrac{1.6 \times 10^{-8}}{6.4 \times 10^{-3}}$

g) $\dfrac{3.00 \times 10^8}{5.2 \times 10^{-7}}$

h) $2.12 \times 10^{12} \times 5.4 \times 10^6$

i) $1.4 \times 10^{-10} \times 1.4 \times 10^{-10} \times 2.2 \times 10^{-10}$

j) $1.6 \times 10^{-19} \times 6.0 \times 10^{23}$

k) $\dfrac{1.3 \times 10^{17}}{3.0 \times 10^8}$

l) $(1.4 \times 10^{-6})^3$

m) $\sqrt{2.5 \times 10^{14}}$

n) $\dfrac{2.0 \times 10^4 \times 1.2 \times 10^4}{(3.2 \times 10^6)^2}$

o) $\dfrac{1.1 \times 10^{-5} \times (-2) \times 3}{(9.6 \times 10^{-11} + 1.2 \times 10^{-10})}$

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B2 Unit conversions

Use standard form where answers are outside the range 0.01 to 1000 units.

B2.1 Convert the following volumes into dm^3

a) $0.86\ m^3$
b) $200\ cm^3$
c) 45 ml
d) $120\ m^3$
e) $0.064\ nm^3$
f) 70 cl
g) $1.6\ mm^3$
h) 1100 cc
i) $2.2\ km^3$
j) $42.5\ Å^3$

B2.2 Converts the following masses into g:

a) 16.0 kg
b) 120 mg
c) 0.004 kg
d) 12 tonne
e) $54\ \mu g$

B2.3 Convert the following into standard SI units:

a) $68\ km\,h^{-1}$
b) 500 g
c) $24\ dm^3$
d) 20 mbar
e) −77 ° C
f) 5.0 h
g) 740 nm
h) $72\ mN\,cm^{-1}$
i) 1014 mbar
j) $13.8\ g\,cm^{-3}$

B2.4 Give the results of the following calculations in standard SI units:

a) Density = $250\ g / 400\ cm^3$
b) Speed = 96 km / 80 min
c) Concentration = $2.50\ mmol / 40.0\ cm^3$ (use $mol\,dm^{-3}$)
d) Momentum = $4.0 \times 10^{-23}\ g \times 900\ m\,s^{-1}$
e) Pressure = $590\ fN / 10\ nm^2$
f) Volume = $240\ pm \times 240\ pm \times 320\ pm$
g) Amount = $2.0\ \mu mol\,dm^{-3} \times 75\ \mu m^3$
h) Energy = $3.2 \times 10^{-19}\ C \times 2.4\ kV$

B3 Gases

16/19

RTP = room temperature and pressure.
Any gas occupies 24 dm^3 per mole at RTP.
Avogadro's number, $N_A = 6.02 \times 10^{23}$.

B3.1 Calculate the volume occupied by:

a) 4.0 moles of gas at RTP

b) 0.030 moles of gas at RTP

c) 5.0×10^{18} atoms of helium gas at RTP

d) 1.2×10^{24} molecules of ozone at RTP

e) 8.0 g of O_2 at RTP

f) 1.1 kg of carbon dioxide at RTP

B3.2 Calculate the amount of gas (at RTP) in:

a) 4.8 dm^3

b) 12 m^3

c) 400 cm^3

d) 18 ml

B3.3 Calculate the number of molecules of gas (at RTP) in:

a) 36 dm^3

b) 300 cm^3

B3.4 Calculate the number of atoms (at RTP) in:

a) 60 cm^3 of argon

b) 1.2 dm^3 of N_2

c) 8.0 m^3 of carbon dioxide

d) 420 cm^3 of ethene

B3.5 Calculate the the mass of:

a) 1.0 m^3 of neon at RTP

b) 20 cm^3 of $(CH_3)_2O$ at RTP

c) 420 cm^3 of ammonia at RTP

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B4 Solids

B4.1 Find the molar masses in amu of the following compounds:

a) $CaCO_3$
b) Na_2CO_3
c) NaOH
d) HCl
e) H_2SO_4
f) $FeSO_4$
g) $KMnO_4$
h) $Fe_2O_3 \cdot 5\,H_2O$ [1]
i) Calcium hydroxide
j) Butane

B4.2 Calculate the mass of:

a) 0.25 moles of H_2O_2(l)
b) 6.0 moles of C_2H_6(g)
c) 0.40 moles of H_2O(l)
d) 20.0 moles of Sr(s)
e) 1.20 moles of aluminium oxide
f) 7.4 moles of ammonium sulfate

B4.3 Calculate the amount of:

a) 1.001 g of $CaCO_3$(s)
b) 197 kg of Au(s)
c) 1.4 g of CO(g)
d) 2.006 kg of Hg(l)
e) 11.1 g of lithium carbonate
f) 10.0 mg of lead(II) iodide

10/12

B5 Solutions

B5.1 Calculate the concentration in mol dm^{-3} of the following solutions:

a) 0.40 g NaOH in 100 ml water
b) 7.3 g HCl in 1000 ml water
c) 2.5 g H_2SO_4 in 50 ml water
d) 15 g $FeSO_4$ in 500 ml water
e) 0.16 g $KMnO_4$ in 200 ml water

B5.2 Calculate the mass of solute in each of the following:

a) 500 ml of 0.010 mol dm^{-3} NaOH
b) 150 ml of 4.0 mol dm^{-3} HCl

---

[1] The 5 means that the formula includes 5 of what follows, i.e. water, so total mass is for $Fe_2O_3 + 5 \times H_2O$

c) 1.00 ml of 10.0 mol dm^{-3} H_2SO_4

d) 25.0 ml of 0.50 mol dm^{-3} $FeSO_4$

e) 21.8 ml of 0.0050 mol dm^{-3} $KMnO_4$

f) 2.0 dm^3 of 0.10 mol dm^{-3} NaCl

g) 100 ml of limewater with a concentration of 0.00020 mol dm^{-3}

B6 Reactions

17/21

B6.1 Calculate the amount of oxygen needed, and amount of carbon dioxide produced, in each of the following cases:

a) $C_3H_8 + 5\,O_2 \longrightarrow 3\,CO_2 + 4\,H_2O$, using 1.0 mole of C_3H_8

b) $C_2H_6O + 3\,O_2 \longrightarrow 2\,CO_2 + 3\,H_2O$, using 0.2 moles of C_2H_6O

c) $2\,CO + O_2 \longrightarrow 2\,CO_2$, using 4.0 moles of CO

d) $C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$, using 0.040 moles of $C_6H_{12}O_6$

e) $C_2H_4O_2 + 2\,O_2 \longrightarrow 2\,CO_2 + 2\,H_2O$, using 0.10 moles of $C_2H_4O_2$

B6.2 Calculate the amount of water produced by complete combustion of the following in oxygen (you will need to write a balanced equation each time):

a) 1.0 mole of pentane, C_5H_{12}

b) 2.5 moles of heptane, C_7H_{16}

c) 200 moles of hydrogen, H_2

d) 4.0 moles of butane

e) 0.0030 moles of methane

B6.3 Write the equation for each reaction and hence calculate the amount of acid required for complete reaction in each of the following cases:

a) 0.10 mol NaOH reacting with H_2SO_4

b) HCl reacting with 20 g of $CaCO_3$

c) 24 g CuO reacting with HNO_3

d) 5.6 g Fe reacting with HCl

e) 14.8 g of calcium hydroxide reacting with H_2SO_4

f) 10 g of magnesium oxide reacting with nitric acid

B6.4 Calculate the volume of 0.50 mol dm^{-3} H_2SO_4 required to neutralize each of the following:

a) 25.0 cm^3 of 1.0 mol dm^{-3} NaOH

b) 3.0 g $CaCO_3$

c) 1.25 g $ZnCO_3$

d) 4.03 kg MgO

e) 100 cm^3 of 0.2 mol dm^{-3} NH_3(aq)

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B7 Titration

B7.1 Nitric acid of unknown concentration was added to a burette. 25.00 cm^3 of potassium hydroxide solution at a concentration of 0.100 mol dm^{-3} was transferred to a 250 cm^3 conical flask using a volumetric pipette. A few drops of methyl orange indicator were added to the flask.

a) Give the colour of the indicator in the alkaline solution in the flask.

The nitric acid was added to the flask a little at a time until the resulting solution went pink. The whole process was repeated until concordant titres (within 0.10 cm^3) were obtained.

b) The concentration of nitric acid was found to be 0.092 mol dm^{-3}. Calculate the titre obtained, in cm^3.

B7.2 In an analysis, 2.50 g of an unknown carbonate were dissolved in 100 cm^3 of 1.00 mol dm^{-3} hydrochloric acid (an excess). The resulting solution was made up to 250 cm^3 in a volumetric flask. 25.00 cm^3 aliquots of this solution were titrated against 0.250 mol dm^{-3} sodium hydroxide. Some of the results are shown below. Fill in the gaps in the table overleaf, and then calculate the quantities below to identify the cation.

TITRATION	Initial burette reading / cm^3	Final burette reading / cm^3	Titre / cm^3
ROUGH	0.60	25.10	(a)
1	0.15	(b)	24.10
2	(c)	25.25	24.45
3	1.35	25.45	(d)

e) Calculate the average concordant titre.

f) Calculate the amount of sodium hydroxide in that volume.

g) Calculate the amount of hydrochloric acid in each aliquot.

h) Calculate the initial amount of hydrochloric acid added to the carbonate.

i) Calculate the amount of hydrochloric acid remaining after reaction.

j) Calculate the amount of hydrochloric acid used in reaction with the carbonate.

k) Calculate the amount of carbonate in 2.50 g.

l) Calculate the molar mass of the carbonate.

m) Identify the cation in the carbonate.

B7.3 All of the ozone in 5.00 m^3 of air was reacted with 250 cm^3 of potassium iodide solution:

$$O_3 + 2\,I^- + 2\,H^+ \longrightarrow I_2 + O_2 + H_2O.$$

The liberated iodine was titrated against a standard solution of sodium thiosulfate with a concentration of 0.0400 $mol\,dm^{-3}$. 25.0 cm^3 of the iodine solution was used in each titration. The results of the titration are shown in the table overleaf. Fill in the remaning titres, and then answer the questions which follow.

TITRATION	Initial burette reading / cm^3	Final burette reading / cm^3	Titre / cm^3
ROUGH	0.10	25.40	25.30
1	0.80	26.10	(a)
2	1.20	26.20	(b)
3	1.00	25.90	(c)

d) Calculate the concentration of the iodine solution.

e) Calculate the amount of ozone in the 5.00 m^3 of air.

f) Name the piece of apparatus that should be used to transfer the iodine solution into a conical flask, ready for titration.

g) Name a suitable indicator for this titration, and give its colour change at the end point.

B7.4 Three students each prepare a standard solution by dissolving 10.6 g of solid from different bottles labelled 'sodium carbonate' in exactly 1 dm^3 of water. They use this standard solution in a titration to determine the exact concentration of a solution of sulphuric acid at approximately 0.1 $mol\,dm^{-3}$. They each use a pipette to measure out exactly 25.00 cm^3 of the standard solution into a conical flask; they use the same indicator and carry out their titrations with great care and accuracy.
The volumes of sulphuric acid solution that they each use are tabulated below. Only student A finds the correct concentration of the sulphuric acid. Student B is within 20% but student C is so far out that they know something is wrong. Student C asks for help and is reminded that some solids can contain water of crystallization. Student A uses anhydrous sodium carbonate, but what is x in the formula $Na_2CO_3 \cdot xH_2O(s)$ for students B and C?

	Student A	Student B	Student B
Volume	23.75 cm^3	20.20 cm^3	8.80 cm^3

a) Calculate the exact concentration of the sulphuric acid.

b) Find x for the two different cases of students B and C.

B8 Parts per million

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B8.1 Calculate the ppm by volume of:

a) 20 cm^3 of CO per 40 m^3 of air

b) 0.10 ml of alcohol per 100 ml of blood

c) 5.0 cm^3 of O_3 per 20 m^3 of air

d) 0.0040 cm^3 of C_2H_4 per 1 dm^3 of air

B8.2 Calculate the ppm by mass of:

a) 10 mg of Hg per tonne of water

b) 0.020 g of Mg per kg of $CaCO_3$

c) 50 mg of iron per kg of blood

d) 4.0×10^{-4} moles of arsenic per 1 kg of iron ore

B8.3 Calculate the ppm by number of particles of:

a) 23 mg of sodium in 2 kg of mercury

b) 60 μmol of albumen in 36 cm^3 of water

c) 12 μg of magnesium hydrogen phosphate in 90 μl of water

d) 84 μg of carbon monoxide in 12 dm^3 of air

B8.4 Convert the following concentrations from parts per million (ppm) by mass to mol kg^{-1}.

a) 2500 ppm $CaCO_3$

b) 32.0 ppm NH_3

c) 120 ppm H_2O_2

d) 0.25 ppm Hg

e) 6.0 ppm $CH_3CH_2CH_2COOH$

The Periodic Table of the Elements

Key
atomic number
Symbol
name
relative atomic mass

(1) 1	(2) 2	3	4	5	6	7	8	9	10	11	12	(3) 13	(4) 14	(5) 15	(6) 16	(7) 17	(0) 18
1 **H** hydrogen 1.0																	2 **He** helium 4.0
3 **Li** lithium 6.9	4 **Be** beryllium 9.0											5 **B** boron 10.8	6 **C** carbon 12.0	7 **N** nitrogen 14.0	8 **O** oxygen 16.0	9 **F** fluorine 19.0	10 **Ne** neon 20.2
11 **Na** sodium 23.0	12 **Mg** magnesium 24.3											13 **Al** aluminium 27.0	14 **Si** silicon 28.1	15 **P** phosphorus 31.0	16 **S** sulfur 32.1	17 **Cl** chlorine 35.5	18 **Ar** argon 39.9
19 **K** potassium 39.1	20 **Ca** calcium 40.1	21 **Sc** scandium 45.0	22 **Ti** titanium 47.9	23 **V** vanadium 50.9	24 **Cr** chromium 52.0	25 **Mn** manganese 54.9	26 **Fe** iron 55.8	27 **Co** cobalt 58.9	28 **Ni** nickel 58.7	29 **Cu** copper 63.5	30 **Zn** zinc 65.4	31 **Ga** gallium 69.7	32 **Ge** germanium 72.6	33 **As** arsenic 74.9	34 **Se** selenium 79.0	35 **Br** bromine 79.9	36 **Kr** krypton 83.8
37 **Rb** rubidium 85.5	38 **Sr** strontium 87.6	39 **Y** yttrium 88.9	40 **Zr** zirconium 91.2	41 **Nb** niobium 92.9	42 **Mo** molybdenum 95.9	43 **Tc** technetium	44 **Ru** ruthenium 101.1	45 **Rh** rhodium 102.9	46 **Pd** palladium 106.4	47 **Ag** silver 107.9	48 **Cd** cadmium 112.4	49 **In** indium 114.8	50 **Sn** tin 118.7	51 **Sb** antimony 121.8	52 **Te** tellurium 127.6	53 **I** iodine 126.9	54 **Xe** xenon 131.3
55 **Cs** caesium 132.9	56 **Ba** ● barium 137.3	57–71 lanthanoids	72 **Hf** hafnium 178.5	73 **Ta** tantalum 180.9	74 **W** tungsten 183.8	75 **Re** rhenium 186.2	76 **Os** osmium 190.2	77 **Ir** iridium 192.2	78 **Pt** platinum 195.1	79 **Au** gold 197.0	80 **Hg** mercury 200.6	81 **Tl** thallium 204.4	82 **Pb** lead 207.2	83 **Bi** bismuth 209.0	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
87 **Fr** francium	88 **Ra** ● radium ●	89–103 actinoids	104 **Rf** rutherfordium	105 **Db** dubnium	106 **Sg** seaborgium	107 **Bh** bohrium	108 **Hs** hassium	109 **Mt** meitnerium	110 **Ds** darmstadtium	111 **Rg** roentgenium	112 **Cn** copernicium		114 **Fl** flerovium		116 **Lv** livermorium		

●	57 **La** lanthanum 138.9	58 **Ce** cerium 140.1	59 **Pr** praseodymium 140.9	60 **Nd** neodymium 144.2	61 **Pm** promethium 144.9	62 **Sm** samarium 150.4	63 **Eu** europium 152.0	64 **Gd** gadolinium 157.2	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 173.0	71 **Lu** lutetium 175.0
●●	89 **Ac** actinium	90 **Th** thorium 232.0	91 **Pa** protactinium	92 **U** uranium 238.1	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