

H2 Chemistry Data Booklet

A-Level H2 (9476) · H2 Chemistry



The Singapore Syllabus

1 Important values, constants and standards

Quantity	Value
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
the Avogadro constant	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
speed of light in a vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
rest mass of proton, ${}^1_1\text{H}$	$m_p = 1.67 \times 10^{-27} \text{ kg}$
rest mass of neutron, ${}^1_0\text{n}$	$m_n = 1.67 \times 10^{-27} \text{ kg}$
rest mass of electron, ${}^0_{-1}\text{e}$	$m_e = 9.11 \times 10^{-31} \text{ kg}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.7 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. $V_m = 24 \text{ dm}^3 \text{ mol}^{-1}$ at r.t.p. (where s.t.p. is expressed as 10^5 Pa [1 bar] and 273 K [0°C], r.t.p. is expressed as $101\,325 \text{ Pa}$ [1 atm] and 293 K [20°C])
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (= $4.18 \text{ J g}^{-1} \text{ K}^{-1}$)

2 Ionisation energies (1st, 2nd, 3rd and 4th) of selected elements, in kJ mol^{-1}

Element	Proton Number	First	Second	Third	Fourth
H	1	1310	–	–	–
He	2	2370	5250	–	–
Li	3	519	7300	11800	–
Be	4	900	1760	14800	21000
B	5	799	2420	3660	25000
C	6	1090	2350	4610	6220
N	7	1400	2860	4590	7480
O	8	1310	3390	5320	7450
F	9	1680	3370	6040	8410
Ne	10	2080	3950	6150	9290
Na	11	494	4560	6940	9540
Mg	12	736	1450	7740	10500
Al	13	577	1820	2740	11600
Si	14	786	1580	3230	4360
P	15	1060	1900	2920	4960
S	16	1000	2260	3390	4540
Cl	17	1260	2300	3850	5150
Ar	18	1520	2660	3950	5770
K	19	418	3070	4600	5860
Ca	20	590	1150	4940	6480
Sc	21	632	1240	2390	7110
Ti	22	661	1310	2720	4170
V	23	648	1370	2870	4600
Cr	24	653	1590	2990	4770

Element	Proton Number	First	Second	Third	Fourth
Mn	25	716	1510	3250	5190
Fe	26	762	1560	2960	5400
Co	27	757	1640	3230	5100
Ni	28	736	1750	3390	5400
Cu	29	745	1960	3350	5690
Zn	30	908	1730	3828	5980
Ga	31	577	1980	2960	6190
Ge	32	762	1540	3300	4390
Br	35	1140	2080	3460	4850
Rb	37	403	2632	3900	5080
Sr	38	548	1060	4120	5440
Ag	47	731	2074	3361	–
Sn	50	707	1410	2940	3930
I	53	1010	1840	3200	4030
Cs	55	376	2420	3300	–
Ba	56	502	966	3390	–
Pb	82	716	1450	3080	4080

3 Bond energies

3(a) Bond energies in diatomic molecules (these are exact values): Homonuclear

Bond	Energy/kJ mol ⁻¹
H-H	436
D-D	442
N≡N	944
O=O	496
F-F	158
Cl-Cl	244
Br-Br	193
I-I	151

3(a) Bond energies in diatomic molecules (these are exact values): Heteronuclear

Bond	Energy/kJ mol ⁻¹
H-F	562
H-Cl	431
H-Br	366
H-I	299
C≡O	1077

3(b) Bond energies in polyatomic molecules (these are average values): Homonuclear

Bond	Energy / kJ mol ⁻¹
C-C	350
C=C	610
C≡C	840
C=C (benzene)	520
N-N	160
N=N	410
O-O	150
Si-Si	222
P-P	200
S-S	264

3(b) Bond energies in polyatomic molecules (these are average values): Heteronuclear

Bond	Energy / kJ mol ⁻¹
C-H	410
C-F	485
C-Cl	340
C-Br	280
C-I	240
C-N	305
C=N	610
C≡N	890
C-O	360
C=O	740
C=O in CO ₂	805
N-H	390
N-Cl	310

Bond	Energy / kJ mol ⁻¹
O-H	460
Si-Cl	359
Si-H	320
Si-O (in SiO ₂ (s))	460
Si=O (in SiO ₂ (g))	640
P-H	320
P-Cl	330
P-O	340
P=O	540
S-H	347
S-Cl	250
S-O	360
S=O	500

4 Standard electrode potential and redox potentials, $E^\ominus$ at 298 K (25 °C)

For ease of reference, two tabulations are given: (a) an extended list in alphabetical order; (b) a shorter list in decreasing order of magnitude, i.e. a redox series.

4(a) $E^\ominus$ in alphabetical order

Electrode reaction	$E^\ominus$ / V	Electrode reaction	$E^\ominus$ / V
$\text{Ag}^+ + \text{e}^- \rightleftharpoons \text{Ag}$	+0.80	$\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$	+1.23
$\text{Al}^{3+} + 3\text{e}^- \rightleftharpoons \text{Al}$	-1.66	$\text{MnO}_4^- + \text{e}^- \rightleftharpoons \text{MnO}_4^{2-}$	+0.56
$\text{Ba}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ba}$	-2.90	$\text{MnO}_4^- + 4\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{MnO}_2 + 2\text{H}_2\text{O}$	+1.67
$\text{Br}_2 + 2\text{e}^- \rightleftharpoons 2\text{Br}^-$	+1.07	$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	+1.52
$\text{Ca}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ca}$	-2.87	$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{NO}_2 + \text{H}_2\text{O}$	+0.81
$\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-$	+1.36	$\text{NO}_3^- + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HNO}_2 + \text{H}_2\text{O}$	+0.94
$2\text{HOCl} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Cl}_2 + 2\text{H}_2\text{O}$	+1.64	$\text{NO}_3^- + 10\text{H}^+ + 8\text{e}^- \rightleftharpoons \text{NH}_4^+ + 3\text{H}_2\text{O}$	+0.87
$\text{ClO}^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{Cl}^- + 2\text{OH}^-$	+0.81	$\text{Na}^+ + \text{e}^- \rightleftharpoons \text{Na}$	-2.71
$\text{Co}^{2+} + 2\text{e}^- \rightleftharpoons \text{Co}$	-0.28	$\text{Ni}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ni}$	-0.25
$\text{Co}^{3+} + \text{e}^- \rightleftharpoons \text{Co}^{2+}$	+1.89	$[\text{Ni}(\text{NH}_3)_6]^{2+} + 2\text{e}^- \rightleftharpoons \text{Ni} + 6\text{NH}_3$	-0.51
$[\text{Co}(\text{NH}_3)_6]^{2+} + 2\text{e}^- \rightleftharpoons \text{Co} + 6\text{NH}_3$	-0.43	$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$	+1.77
$\text{Cr}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cr}$	-0.91	$\text{HO}_2^- + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons 3\text{OH}^-$	+0.88
$\text{Cr}^{3+} + 3\text{e}^- \rightleftharpoons \text{Cr}$	-0.74	$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$	+1.23
$\text{Cr}^{3+} + \text{e}^- \rightleftharpoons \text{Cr}^{2+}$	-0.41	$\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightleftharpoons 4\text{OH}^-$	+0.40
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	+1.33	$\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2$	+0.68
$\text{Cu}^+ + \text{e}^- \rightleftharpoons \text{Cu}$	+0.52	$\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{HO}_2^- + \text{OH}^-$	-0.08
$\text{Cu}^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu}$	+0.34	$2\text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{H}_2 + 2\text{OH}^-$	-0.83
$\text{Cu}^{2+} + \text{e}^- \rightleftharpoons \text{Cu}^+$	+0.15	$\text{Pb}^{2+} + 2\text{e}^- \rightleftharpoons \text{Pb}$	-0.13
$[\text{Cu}(\text{NH}_3)_4]^{2+} + 2\text{e}^- \rightleftharpoons \text{Cu} + 4\text{NH}_3$	-0.05	$\text{Pb}^{4+} + 2\text{e}^- \rightleftharpoons \text{Pb}^{2+}$	+1.69
$\text{F}_2 + 2\text{e}^- \rightleftharpoons 2\text{F}^-$	+2.87	$\text{PbO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Pb}^{2+} + 2\text{H}_2\text{O}$	+1.47
$\text{Fe}^{2+} + 2\text{e}^- \rightleftharpoons \text{Fe}$	-0.44	$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{SO}_2 + 2\text{H}_2\text{O}$	+0.17
$\text{Fe}^{3+} + 3\text{e}^- \rightleftharpoons \text{Fe}$	-0.04	$\text{S}_2\text{O}_8^{2-} + 2\text{e}^- \rightleftharpoons 2\text{SO}_4^{2-}$	+2.01
$\text{Fe}^{3+} + \text{e}^- \rightleftharpoons \text{Fe}^{2+}$	+0.77	$\text{S}_4\text{O}_6^{2-} + 2\text{e}^- \rightleftharpoons 2\text{S}_2\text{O}_3^{2-}$	+0.09
$[\text{Fe}(\text{CN})_6]^{3-} + \text{e}^- \rightleftharpoons [\text{Fe}(\text{CN})_6]^{4-}$	+0.36	$\text{Sn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Sn}$	-0.14
$\text{Fe}(\text{OH})_3 + \text{e}^- \rightleftharpoons \text{Fe}(\text{OH})_2 + \text{OH}^-$	-0.56	$\text{Sn}^{4+} + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}$	+0.15
$2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2$	0.00	$\text{V}^{2+} + 2\text{e}^- \rightleftharpoons \text{V}$	-1.20
$\text{I}_2 + 2\text{e}^- \rightleftharpoons 2\text{I}^-$	+0.54	$\text{V}^{3+} + \text{e}^- \rightleftharpoons \text{V}^{2+}$	-0.26
$\text{K}^+ + \text{e}^- \rightleftharpoons \text{K}$	-2.92	$\text{VO}^{2+} + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$	+0.34
$\text{Li}^+ + \text{e}^- \rightleftharpoons \text{Li}$	-3.04	$\text{VO}_2^+ + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+} + \text{H}_2\text{O}$	+1.00
$\text{Mg}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mg}$	-2.38	$\text{VO}_3^- + 4\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+} + 2\text{H}_2\text{O}$	+1.00
$\text{Mn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mn}$	-1.18	$\text{Zn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Zn}$	-0.76
$\text{Mn}^{3+} + \text{e}^- \rightleftharpoons \text{Mn}^{2+}$	+1.54		

- All ionic states refer to aqueous ions but other state symbols have been omitted.

4(b) $E^\ominus$ in decreasing order of oxidising power (a selection only – see also the extended alphabetical list on the previous pages)

Electrode reaction	$E^\ominus$ / V	Electrode reaction	$E^\ominus$ / V
$F_2 + 2e^- \rightleftharpoons 2F^-$	+2.87	$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01	$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77	$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1.52	$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0.15
$PbO_2 + 4H^+ + 2e^- \rightleftharpoons Pb^{2+} + 2H_2O$	+1.47	$S_4O_6^{2-} + 2e^- \rightleftharpoons 2S_2O_3^{2-}$	+0.09
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36	$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33	$Pb^{2+} + 2e^- \rightleftharpoons Pb$	-0.13
$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23	$Sn^{2+} + 2e^- \rightleftharpoons Sn$	-0.14
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1.07	$Fe^{2+} + 2e^- \rightleftharpoons Fe$	-0.44
$NO_3^- + 10H^+ + 8e^- \rightleftharpoons NH_4^+ + 3H_2O$	+0.87	$Zn^{2+} + 2e^- \rightleftharpoons Zn$	-0.76
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$	+0.81	$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	-0.83
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+0.81	$V^{2+} + 2e^- \rightleftharpoons V$	-1.20
$Ag^+ + e^- \rightleftharpoons Ag$	+0.80	$Mg^{2+} + 2e^- \rightleftharpoons Mg$	-2.38
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77	$Ca^{2+} + 2e^- \rightleftharpoons Ca$	-2.87
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0.54	$K^+ + e^- \rightleftharpoons K$	-2.92

5 Atomic and ionic radii

(a) Period 1

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
single covalent	H	0.037			H ⁻	0.208
van der Waals	He	0.140				

(b) Period 2

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
metallic	Li	0.152	Li ⁺	0.060		
	Be	0.112	Be ²⁺	0.031		
single covalent	B	0.080	B ³⁺	0.020		
	C	0.077	C ⁴⁺	0.015	C ⁴⁻	0.260
	N	0.074			N ³⁻	0.171
	O	0.073			O ²⁻	0.140
	F	0.072			F ⁻	0.136
van der Waals	Ne	0.160				

(c) Period 3

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
metallic	Na	0.186	Na ⁺	0.095		
	Mg	0.160	Mg ²⁺	0.065		
	Al	0.143	Al ³⁺	0.050		
single covalent	Si	0.117	Si ⁴⁺	0.041		
	P	0.110			P ³⁻	0.212
	S	0.104			S ²⁻	0.184
	Cl	0.099			Cl ⁻	0.181
van der Waals	Ar	0.190				

(d) Group 2

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
metallic	Be	0.112	Be ²⁺	0.031		
	Mg	0.160	Mg ²⁺	0.065		
	Ca	0.197	Ca ²⁺	0.099		
	Sr	0.215	Sr ²⁺	0.113		
	Ba	0.217	Ba ²⁺	0.135		
	Ra	0.220	Ra ²⁺	0.140		

(e) Group 14

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
single covalent	C	0.077				
	Si	0.117	Si ⁴⁺	0.041		
	Ge	0.122	Ge ²⁺	0.093		
metallic	Sn	0.162	Sn ²⁺	0.112		
	Pb	0.175	Pb ²⁺	0.120		

(f) Group 17

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
single covalent	F	0.072			F ⁻	0.136
	Cl	0.099			Cl ⁻	0.181
	Br	0.114			Br ⁻	0.195
	I	0.133			I ⁻	0.216
	At	0.140				

(g) First row d block elements

	Element	atomic/nm	Ion	ionic/nm	Ion	ionic/nm
metallic	Sc	0.164			Sc ³⁺	0.075
	Ti	0.146	Ti ²⁺	0.086	Ti ³⁺	0.067
	V	0.135	V ²⁺	0.079	V ³⁺	0.064
	Cr	0.129	Cr ²⁺	0.073	Cr ³⁺	0.062
	Mn	0.132	Mn ²⁺	0.083	Mn ³⁺	0.058
	Fe	0.126	Fe ²⁺	0.061	Fe ³⁺	0.055
	Co	0.125	Co ²⁺	0.065	Co ³⁺	0.055
	Ni	0.124	Ni ²⁺	0.069	Ni ³⁺	0.056
	Cu	0.128	Cu ²⁺	0.073		
	Zn	0.135	Zn ²⁺	0.074		

6 Typical proton (^1H) chemical shift values (δ) relative to TMS = 0

Type of proton	Environment of proton	Example structures	Chemical Shift range (δ)
C-H	alkane	$-\text{CH}_3$, $-\text{CH}_2-$, $>\text{CH}-$	0.9–1.7
	alkyl next to $\text{C}=\text{O}$	$\text{CH}_3-\text{C}=\text{O}$, $-\text{CH}_2-\text{C}=\text{O}$, $>\text{CH}-\text{C}=\text{O}$	2.2–3.0
	alkyl next to aromatic ring	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
	alkyl next to electronegative atom	CH_3-O , $-\text{CH}_2-\text{O}$, $-\text{CH}_2-\text{Cl}$, $>\text{CH}-\text{Br}$	3.2–4.0
	attached to alkyne	$\equiv\text{C}-\text{H}$	1.8–3.1
	attached to alkene	$=\text{CH}_2$, $=\text{CH}-$	4.5–6.0
	attached to aromatic ring	$\text{C}_6\text{H}_5-\text{H}$	6.0–9.0
	aldehyde	$\text{R}-\text{C}(=\text{O})-\text{H}$	9.3–10.5
O-H (see note below)	alcohol	$\text{RO}-\text{H}$	0.5–6.0
	phenol	$\text{C}_6\text{H}_5-\text{OH}$	4.5–7.0
	carboxylic acid	$\text{R}-\text{C}(=\text{O})-\text{O}-\text{H}$	9.0–13.0
N-H (see note below)	alkyl amine	$\text{R}-\text{NH}-$	1.0–5.0
	aryl amine	$\text{C}_6\text{H}_5-\text{NH}_2$	3.0–6.0
	amide	$\text{R}-\text{C}(=\text{O})-\text{NH}-$	5.0–12.0

- Note: δ values for $-\text{O}-\text{H}$ and $-\text{N}-\text{H}$ protons can vary depending on solvent and concentration.
- Example structures drawn as skeletal diagrams in the booklet ($>\text{CH}-$, the benzene ring, and the $\text{R}-\text{C}(=\text{O})-$ groups) are given here as condensed formulae.

7 Characteristic infra-red absorption frequencies for some selected bonds

Bond	Functional groups containing the bond	Absorption range (in wavenumbers) / cm^{-1}	Appearance of peak (s = strong, w = weak)
C-Cl	chloroalkanes	700–800	s
C-O	alcohol	970–1260	s
	ether	1000–1310	s
	ester	1050–1330	s
	carboxylic acids	1210–1440	s
C=C	aromatic	1475–1625	s
	alkenes	1635–1690	w
C=O	amides	1640–1690	s
	ketones and aldehydes	1670–1740	s
	carboxylic acids	1680–1730	s
	esters	1710–1750	s
C$\equiv$C	alkynes	2150–2250	w unless conjugated
C$\equiv$N	nitriles	2200–2250	w
C-H	alkanes, CH_2-H	2850–2950	s
	alkenes/arenes, $=\text{C}-\text{H}$	3000–3100	w
N-H	amines, amides	3300–3500	w
O-H	carboxylic acid, RCO_2-H	2500–3000	s and very broad
	H-bonded alcohol/phenol, $\text{RO}-\text{H}$	3200–3600	s
	free alcohol, $\text{RO}-\text{H}$	3580–3650	s and sharp

8 The orientating effect of groups in aromatic substitution reactions

The position of the incoming group, E, is determined by the nature of the group, G, already bonded to the ring, and not by the nature of the incoming group E.

G	Reactivity of ring (compared to benzene)	Position of E (relative to position of G)
-alkyl -OH or -OR -NH ₂ , -NHR or -NR ₂ -NHCOR	Activated	2- and/or 4-
-Cl, -Br, -I	Deactivated	2- and/or 4-
-CHO, -COR -CO ₂ H, -CO ₂ R -NH ₃ ⁺ -NO ₂ , -CN	Deactivated	3-

- The booklet prints this table with G, reactivity and position as rows. Here they are columns.
- Scheme printed above the table: a benzene ring bearing G (ring positions 2, 3 and 4 numbered from G) + E⁺ → the ring bearing G and E + H⁺.

9 Qualitative Analysis Notes

[ppt. = precipitate]

9(a) Reactions of aqueous cations

cation	reaction with NaOH(aq)	reaction with NH ₃ (aq)
aluminium, Al ³⁺ (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH ₄ ⁺ (aq)	ammonia produced on heating	–
barium, Ba ²⁺ (aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca ²⁺ (aq)	white ppt. with high [Ca ²⁺ (aq)]	no ppt.
chromium(III), Cr ³⁺ (aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu ²⁺ (aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe ²⁺ (aq)	green ppt., turning brown on contact with air insoluble in excess	green ppt., turning brown on contact with air insoluble in excess
iron(III), Fe ³⁺ (aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg ²⁺ (aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn ²⁺ (aq)	off-white ppt., rapidly turning brown on contact with air insoluble in excess	off-white ppt., rapidly turning brown on contact with air insoluble in excess
zinc, Zn ²⁺ (aq)	white ppt. soluble in excess	white ppt. soluble in excess

9(b) Reactions of anions

anion	reaction
carbonate, CO ₃ ²⁻	CO ₂ liberated by dilute acids
chloride, Cl ⁻ (aq)	gives white ppt. with Ag ⁺ (aq) (soluble in NH ₃ (aq))
bromide, Br ⁻ (aq)	gives pale cream ppt. with Ag ⁺ (aq) (partially soluble in NH ₃ (aq))
iodide, I ⁻ (aq)	gives yellow ppt. with Ag ⁺ (aq) (insoluble in NH ₃ (aq))
nitrate, NO ₃ ⁻ (aq)	NH ₃ liberated on heating with OH ⁻ (aq) and Al foil
nitrite, NO ₂ ⁻ (aq)	NH ₃ liberated on heating with OH ⁻ (aq) and Al foil; NO liberated by dilute acids (colourless NO → (pale) brown NO ₂ in air)
sulfate, SO ₄ ²⁻ (aq)	gives white ppt. with Ba ²⁺ (aq) (insoluble in excess dilute strong acids)
sulfite, SO ₃ ²⁻ (aq)	SO ₂ liberated with dilute acids; gives white ppt. with Ba ²⁺ (aq) (soluble in dilute strong acids)

9(c) Tests for gases

gas	test and test result
ammonia, NH ₃	turns damp red litmus paper blue
carbon dioxide, CO ₂	gives a white ppt. with limewater (ppt. dissolves with excess CO ₂)
chlorine, Cl ₂	bleaches damp litmus paper
hydrogen, H ₂	“pops” with a lighted splint
oxygen, O ₂	relights a glowing splint
sulfur dioxide, SO ₂	turns aqueous acidified potassium manganate(VII) from purple to colourless

9(d) Colour of halogens

halogen	colour of element	colour in aqueous solution	colour in hexane
chlorine, Cl ₂	greenish yellow gas	pale yellow	pale yellow
bromine, Br ₂	reddish brown gas / liquid	orange	orange-red
iodine, I ₂	black solid / purple gas	brown	purple

10 The Periodic Table of Elements

Key: atomic number, atomic symbol, name, relative atomic mass

The Periodic Table of Elements, with the values printed in the data booklet

proton number Symbol relative atomic mass																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1 H 1.0																	2 He 4.0		
3 Li 6.9	4 Be 9.0												5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2	
11 Na 23.0	12 Mg 24.3												13 Al 27.0	14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9	
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.8	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8		
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc -	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3		
55 Cs 132.9	56 Ba 137.3	57-71	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po -	85 At -	86 Rn -		
87 Fr -	88 Ra -	89-103	104 Rf -	105 Db -	106 Sg -	107 Bh -	108 Hs -	109 Mt -	110 Ds -	111 Rg -	112 Cn -	113 Nh -	114 Fl -	115 Mc -	116 Lv -	117 Ts -	118 Og -		
lanthanoids		57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm -	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.1	71 Lu 175.0			
actinoids		89 Ac -	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np -	94 Pu -	95 Am -	96 Cm -	97 Bk -	98 Cf -	99 Es -	100 Fm -	101 Md -	102 No -	103 Lr -			