Data Booklet for Chemistry (Advanced Level)

TABLES OF CHEMICAL DATA

Important values, constants and standards

molar gas constant	R	= 8.31 J K^{-1} mol^{-1}
the Faraday constant	F	= 9.65 x 10^{4} C mol^{-1}
the Avogadro constant	L	= 6.02 x 10^{23} mol^{-1}
the Planck constant	h	= 6.63 x 10^{-34} J s
speed of light in a vacuum	c	= 3.00 x 10^{8} m s^{-1}
rest mass of proton, $^{1}_{1}H$	m_p	= 1.67 x 10^{-27} kg
rest mass of neutron, $^{1}_{0}n$	m_n	= 1.67 x 10^{-27} kg
rest mass of electron, $^{0}_{-1}e$	m_e	= 9.11 x 10^{-31} kg
electronic charge	e	= -1.60 x 10^{-19} C
molar volume of gas	V_m	= 22.4 dm^3 mol^{-1} at s.t.p.
	V_m	= 24 dm^3 mol^{-1} under room conditions

(where s.t.p. is expressed as 101 kPa, approximately, and 273 K (0 °C))

ionic product of water	K_w	= 1.00 x 10^{-14} mol^2 dm^{-6} (at 298 K [25 °C])
specific heat capacity of water		= 4.18 kJ kg^{-1} K^{-1} (= 4.18 J g^{-1} K^{-1})

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

	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
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
Sr	38	548	1060	4120	5440
Sn	50	707	1410	2940	3930
I	53	1010	1840	2040	4030
Ba	56	502	966	3390	-
Pb	82	716	1450	3080	4080

Bond energies

(a) Diatomic molecules

Bond	Energy/kJ mol^{-1}
H—H	436
D—D	442
N≡N	994
O=O	496
F—F	158
Cl—Cl	244
Br—Br	193
I—I	151
H—F	562
H—Cl	431
H—Br	366
H—I	299

(b) Polyatomic molecules

Bond	Energy/kJ mol^{-1}
C—C	350
C=C	610
C≡C	840
C⁻⁻C (benzene)	520
C—H	410
C—Cl	340
C—Br	280
C—I	240
C—O	360
C=O	740
C—N	305
C=N	610
C≡N	890
N—H	390
N—N	160
N=N	410
O—H	460
O—O	150
Si—Cl	359
Si—H	320
Si—O	444
Si—Si	222
S— Cl	250
S—H	347
S—S	264

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.

(a) $E^{\ominus}$ **in** alphabetical **order**

Electrode reaction			$E^{\ominus}$/V
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+0.80
$Al^{3+} + 3e^-$	$\rightleftharpoons$	Al	-1.66
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	Ba	-2.90
$Br_2 + 2e^-$	$\rightleftharpoons$	$2Br^-$	+1.07
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	Ca	-2.87
$Cl_2 + 2e^-$	$\rightleftharpoons$	$2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^-$	$\rightleftharpoons$	$Cl_2 + 2H_2O$	+1.64
$Co^{2+} + 2e^-$	$\rightleftharpoons$	Co	-0.28
$Co^{3+} + e^-$	$\rightleftharpoons$	Co^{2+}	+1.82
$[Co(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Co + 6NH_3$	-0.43
$Cr^{2+} + 2e^-$	$\rightleftharpoons$	Cr	-0.91
$Cr^{3+} + 3e^-$	$\rightleftharpoons$	Cr	-0.74
$Cr^{3+} + e^-$	$\rightleftharpoons$	Cr^{2+}	-0.41
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	$\rightleftharpoons$	$2Cr^{3+} + 7H_2O$	+1.33
$Cu^+ + e^-$	$\rightleftharpoons$	Cu	+0.52
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$Cu^{2+} + e^-$	$\rightleftharpoons$	Cu^+	+0.15
$[Cu(NH_3)_4]^{2+} + 2e^-$	$\rightleftharpoons$	$Cu + 4NH_3$	-0.05
$F_2 + 2e^-$	$\rightleftharpoons$	$2F^-$	+2.87
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	-0.44
$Fe^{3+} + 3e^-$	$\rightleftharpoons$	Fe	-0.04
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+0.77
$[Fe(CN)_6]^{3-} + e^-$	$\rightleftharpoons$	$[Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_3 + e^-$	$\rightleftharpoons$	$Fe(OH)_2 + OH$	-0.56
$2H^+ + 2e^-$	$\rightleftharpoons$	H_2	0.00
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$	+0.54
$K^+ + e^-$	$\rightleftharpoons$	K	-2.92
$Li^+ + e^-$	$\rightleftharpoons$	Li	-3.04
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg	-2.38
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	Mn	-1.18
$Mn^{3+} + e^-$	$\rightleftharpoons$	Mn^{2+}	+1.49
$MnO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Mn^{2+} + 2H_2O$	+1.23
$MnO_4^- + e^-$	$\rightleftharpoons$	MnO_4^{2-}	+0.56
$MnO_4^- + 4H^+ + 3e^-$	$\rightleftharpoons$	$MnO_2 + 2H_2O$	+1.67
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	+1.52
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$	$NO_2 + H_2O$	+0.81
$NO_3^- + 3H^+ + 2e^-$	$\rightleftharpoons$	$HNO_2 + H_2O$	+0.94
$NO_3^- + 10H^+ + 8e^-$	$\rightleftharpoons$	$NH_4^+ + 3H_2O$	+0.87
$Na^+ + e^-$	$\rightleftharpoons$	Na	-2.71
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	Ni	-0.25

$[Ni(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Ni + 6NH_3$	-0.51
$H_2O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	$2H_2O$	+1.77
$O_2 + 4H^+ + 4e^-$	$\rightleftharpoons$	$2H_2O$	+1.23
$O_2 + 2H_2O + 4e^-$	$\rightleftharpoons$	$4OH^-$	+0.40
$O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O_2	+0.68
$2H_2O + 2e^-$	$\rightleftharpoons$	$H_2 + 2OH^-$	-0.83
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	-0.13
$Pb^{4+} + 2e^-$	$\rightleftharpoons$	Pb^{2+}	+1.69
$PbO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Pb^{2+} + 2H_2O$	+1.47
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2 + 2H_2O$	+0.17
$S_2O_8^{2-} + 2e^-$	$\rightleftharpoons$	$2SO_4^{2-}$	+2.01
$S_4O_6^{2-} + 2e^-$	$\rightleftharpoons$	$2S_2O_3^{2-}$	+0.09
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	Sn	-0.14
$Sn^{4+} + 2e^-$	$\rightleftharpoons$	Sn^{2+}	+0.15
$V^{2+} + 2e^-$	$\rightleftharpoons$	V	-1.20
$V^{3+} + e^-$	$\rightleftharpoons$	V^{2+}	-0.26
$VO^{2+} + 2H^+ + e^-$	$\rightleftharpoons$	$V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^-$	$\rightleftharpoons$	$VO^{2+} + H_2O$	+1.00
$VO_3^- + 4H^+ + e^-$	$\rightleftharpoons$	$VO^{2+} + 2H_2O$	+1.00
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn	-0.76

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

(b) $E^\ominus$ in decreasing order of oxidising power

(see also the extended alphabetical list on the previous pages)

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

$Mg^{2+} + 2e^-$	⇌	Mg	-2.38
$Ca^{2+} + 2e^-$	⇌	Ca	-2.87
$K^+ + e^-$	⇌	K	-2.92

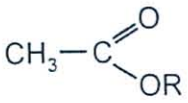
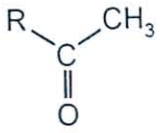
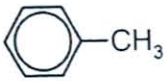
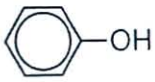
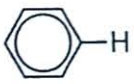
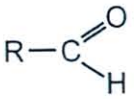
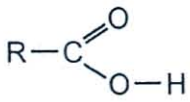
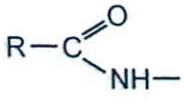
Atomic and ionic radii

			atomic/nm		ionic/nm
(a)	**Period 3**				
	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	0.192		
(b)	**Group II**				
	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
(c)	**Group IV**				
	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
(d)	**Group VII**				
	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		
(e)	**First row transition elements**				
	single covalent	Sc	0.144	Sc^{3+}	0.081
		Ti	0.132	Ti^{2+}	0.090
		V	0.122	V^{3+}	0.074
		Cr	0.117	Cr^{3+}	0.069
		Mn	0.117	Mn^{2+}	0.080
		Fe	0.116	Fe^{2+}	0.076
				Fe^{3+}	0.064
		Co	0.116	Co^{2+}	0.078
		Ni	0.115	Ni^{2+}	0.078
		Cu	0.117	Cu^{2+}	0.069
		Zn	0.125	Zn^{2+}	0.074

Characteristic values for infra-red absorption (due to stretching vibrations in organic molecules).

Bond		Characteristic ranges Wavenumber (reciprocal wavelength) /cm^{-1}
C—C*l*		700 to 800
C—O	alcohols, ethers, esters	1000 to 1300
C=C		1610 to 1680
C=O	aldehydes, ketones, acids, esters	1680 to 1750
C≡C		2070 to 2250
C≡N		2200 to 2280
O—H	'hydrogen-bonded' in acids	2500 to 3300
C—H	alkanes, alkenes, arenes	2840 to 3095
O—H	'hydrogen-bonded' in alcohols, phenols	3230 to 3550
N—H	primary amines	3350 to 3500
O—H	'free'	3580 to 3650

Typical proton chemical shift value (δ) relative to T.M.S.=0

Type of proton	*Chemical shift (ppm)*
$R-CH_3$	0.9
$R-CH_2-R$	1.3
R_3CH	1.4–1.7
	2.0
	2.1
	2.3
$R-C\equiv C-H$	1.8–3.1
$R-CH_2-Hal$	3.2–3.7
$R-O-CH_3$	3.3–4.0
$R-O-H$	0.5–6.0*
$R_2C=CH-$	4.5–6.0
	4.5–7.0*
	6.0–9.0
	9.0–10.0
	9.0–13.0*
$R-NH_2$	1.0–5.0*
	3.0–6.0*
	5.0–12.0*

*Sensitive to solvent, concentration

The Periodic Table of the Elements

Group I	Group II											Group III	Group IV	Group V	Group VI	Group VII	Group 0
							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 sulphur 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	– 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	– Po polonium 84	– At astatine 85	– Rn radon 86
– Fr francium 87	– Ra radium 88	– Ac actinium 89 * *	– Rf rutherfordium 104	– Db dubnium 105	– Sg seaborgium 106	– Bh bohrium 107	– Hs hassium 108	– Mt meitnerium 109	– Unu ununnilium 110	– Uuu ununnium 111	– Uub ununbium 112		– Uuq ununquadium 114		– Uuh ununhexium 116		– Uuo ununoctium 118

Key

relative atomic mass
atomic symbol
name
atomic number

lanthanides *	140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	– 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
actinides * *	– Th thorium 90	– Pa protactinium 91	– U uranium 92	– Np neptunium 93	– Pu plutonium 94	– Am americium 95	– Cm curium 96	– Bk berkelium 97	– Cf californium 98	– Es einsteinium 99	– Fm fermium 100	– Md mendelevium 101	– No nobelium 102	– Lw lawrencium 103