Diploma Programme

Chemistry data booklet

For use during the course and in the examinations
First assessment 2025

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Chemistry data booklet

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Introduction

This Diploma Programme (DP) *Chemistry data booklet* accompanies the DP *Chemistry guide* and DP *Chemistry teacher support material*. It contains chemical and physical equations and constants, chemical symbols, the periodic table, and other chemical data relevant to the course.

Students must have access to a copy of this booklet for the duration of the course, so that they can become familiar with its contents. Direct reference is made to relevant equations in the "Understandings" sections of the guide. This helps to maintain the emphasis on interpretation and application rather than memorization of symbols, constants and equations.

Each student must have access to a clean copy of the *Chemistry data booklet* during examinations. It is the responsibility of the school to download a copy of this booklet from IBIS or the Programme Resource Centre and to ensure that there are sufficient copies available for all students.

1. Some relevant equations

Equation
$c = f\lambda$
$E = hf$
$n = \frac{m}{M}$
$n = CV$
$PV = nRT$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
$Q = mc\Delta T$
$\%\ \text{atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100$
$\Delta H^{\ominus} = \sum(\Delta H_f^{\ominus}{}_{\text{products}}) - \sum(\Delta H_f^{\ominus}{}_{\text{reactants}})$
$\Delta H^{\ominus} = \sum(\Delta H_c^{\ominus}{}_{\text{reactants}}) - \sum(\Delta H_c^{\ominus}{}_{\text{products}})$
$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$
$\Delta G = \Delta G^{\ominus} + RT \ln Q$
$\Delta G^{\ominus} = -RT \ln K$
$\Delta G^{\ominus} = -nFE^{\ominus}$
$k = Ae^{\frac{-E_a}{RT}}$
$\ln k = \frac{-E_a}{RT} + \ln A$
$\text{pH} = -\log_{10}[H_3O^+]$ or $\text{pH} = -\log_{10}[H^+]$
$K_w = [H^+][OH^-]$
$\text{pOH} = -\log_{10}[OH^-]$

2. Physical constants

Quantity	Symbol	Approximate value
Elementary charge	e	1.602177×10^{-19} C
Electron rest mass	m_e	9.109384×10^{-31} kg
Proton rest mass	m_p	1.672622×10^{-27} kg
Neutron rest mass	m_n	1.674927×10^{-27} kg
Speed of light in vacuum	c	3.00×10^{8} m s^{-1}
Planck constant	h	6.63×10^{-34} J s
Avogadro constant	N_A	6.02×10^{23} mol^{-1}
Gas constant	R	8.31 J K^{-1} mol^{-1}
Molar volume of an ideal gas at STP	V_m	2.27×10^{-2} m^3 mol^{-1} = 22.7 dm^3 mol^{-1}
Specific heat capacity of water	c_w	4.18 kJ kg^{-1} K^{-1} = 4.18 J g^{-1} K^{-1}
Ionic product constant for water at 298.15 K	K_w	1.00×10^{-14} mol^2 dm^{-6}
Faraday constant	F	9.65×10^{4} C mol^{-1}

3. Metric (SI) multipliers

Prefix	Abbreviation	Value
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

4. Unit conversions and standard conditions

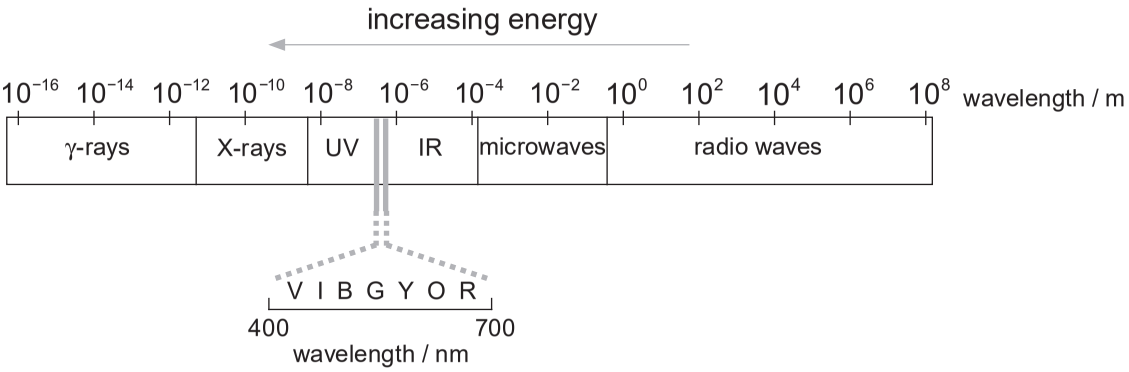
Temperature (K) = temperature (°C) + 273.15

$1 dm^3 = 1$ litre $= 1 \times 10^{-3}\ m^3 = 1 \times 10^3\ cm^3$

STP conditions: 273.15 K and 100 kPa

SATP conditions: 298.15 K and 100 kPa

5. The electromagnetic spectrum



6. Names of the elements

Element	Symbol	Atomic number
actinium	Ac	89
aluminium	Al	13
americium	Am	95
antimony	Sb	51
argon	Ar	18
arsenic	As	33
astatine	At	85
barium	Ba	56
berkelium	Bk	97
beryllium	Be	4
bismuth	Bi	83
bohrium	Bh	107
boron	B	5
bromine	Br	35
cadmium	Cd	48
caesium	Cs	55
calcium	Ca	20
californium	Cf	98
carbon	C	6
cerium	Ce	58
chlorine	Cl	17
chromium	Cr	24
cobalt	Co	27
copernicium	Cn	112
copper	Cu	29
curium	Cm	96
darmstadtium	Ds	110
dubnium	Db	105

Element	Symbol	Atomic number
dysprosium	Dy	66
einsteinium	Es	99
erbium	Er	68
europium	Eu	63
fermium	Fm	100
flerovium	Fl	114
fluorine	F	9
francium	Fr	87
gadolinium	Gd	64
gallium	Ga	31
germanium	Ge	32
gold	Au	79
hafnium	Hf	72
hassium	Hs	108
helium	He	2
holmium	Ho	67
hydrogen	H	1
indium	In	49
iodine	I	53
iridium	Ir	77
iron	Fe	26
krypton	Kr	36
lanthanum	La	57
lawrencium	Lr	103
lead	Pb	82
lithium	Li	3
livermorium	Lv	116
lutetium	Lu	71

Element	Symbol	Atomic number
magnesium	Mg	12
manganese	Mn	25
meitnerium	Mt	109
mendelevium	Md	101
mercury	Hg	80
molybdenum	Mo	42
moscovium	Mc	115
neodymium	Nd	60
neon	Ne	10
neptunium	Np	93
nickel	Ni	28
nihonium	Nh	113
niobium	Nb	41
nitrogen	N	7
nobelium	No	102
oganesson	Og	118
osmium	Os	76
oxygen	O	8
palladium	Pd	46
phosphorus	P	15
platinum	Pt	78
plutonium	Pu	94
polonium	Po	84
potassium	K	19
praseodymium	Pr	59
promethium	Pm	61
protactinium	Pa	91
radium	Ra	88
radon	Rn	86
rhenium	Re	75
rhodium	Rh	45

Element	Symbol	Atomic number
roentgenium	Rg	111
rubidium	Rb	37
ruthenium	Ru	44
rutherfordium	Rf	104
samarium	Sm	62
scandium	Sc	21
seaborgium	Sg	106
selenium	Se	34
silicon	Si	14
silver	Ag	47
sodium	Na	11
strontium	Sr	38
sulfur	S	16
tantalum	Ta	73
technetium	Tc	43
tellurium	Te	52
tennessine	Ts	117
terbium	Tb	65
thallium	Tl	81
thorium	Th	90
thulium	Tm	69
tin	Sn	50
titanium	Ti	22
tungsten	W	74
uranium	U	92
vanadium	V	23
xenon	Xe	54
ytterbium	Yb	70
yttrium	Y	39
zinc	Zn	30
zirconium	Zr	40

7. The periodic table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.01						Atomic number **Element** Relative atomic mass											2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La †** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.20	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 **Ac ‡** (227)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (269)	107 **Bh** (270)	108 **Hs** (269)	109 **Mt** (278)	110 **Ds** (281)	111 **Rg** (281)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289)	115 **Mc** (288)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

†	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
‡	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

8. Melting points and boiling points of the elements at 101.325 kPa

−259.2 **H** −252.9					Melting point / °C **Element** Boiling point / °C												**He** −268.9
180.5 **Li** 1342	1287 **Be** 2468											2077 **B** 4000	3500 **C** 4827	−210.0 **N** −195.8	−218.8 **O** −183.0	−219.7 **F** −188.1	−248.6 **Ne** −246.0
97.79 **Na** 882.9	650.0 **Mg** 1090											660.3 **Al** 2519	1414 **Si** 3265	44.15 **P** 280.5	115.2 **S** 444.6	−101.5 **Cl** −34.04	−189.3 **Ar** −185.8
63.38 **K** 758.8	842.0 **Ca** 1484	1541 **Sc** 2836	1670 **Ti** 3287	1910 **V** 3407	1907 **Cr** 2671	1246 **Mn** 2061	1538 **Fe** 2861	1495 **Co** 2927	1455 **Ni** 2913	1085 **Cu** 2560	419.5 **Zn** 907.0	29.77 **Ga** 2229	938.2 **Ge** 2833	816.8 **As** 613.0	220.8 **Se** 684.8	−7.050 **Br** 58.78	−157.4 **Kr** −153.4
39.30 **Rb** 687.8	768.8 **Sr** 1377	1522 **Y** 3345	1854 **Zr** 4406	2477 **Nb** 4741	2622 **Mo** 4639	2157 **Tc** 4262	2333 **Ru** 4147	1963 **Rh** 3695	1555 **Pd** 2963	961.8 **Ag** 2162	321.1 **Cd** 766.8	156.6 **In** 2027	231.9 **Sn** 2586	630.6 **Sb** 1587	449.5 **Te** 987.8	113.7 **I** 184.4	−111.8 **Xe** −108.1
28.44 **Cs** 670.8	725.0 **Ba** 1845	920.0 **La** † 3464	2233 **Hf** 4600	3017 **Ta** 5455	3414 **W** 5555	3453 **Re** 5900	3033 **Os** 5008	2446 **Ir** 4428	1768 **Pt** 3825	1064 **Au** 2836	−38.83 **Hg** 356.6	303.8 **Tl** 1473	327.5 **Pb** 1749	271.4 **Bi** 1564	253.8 **Po** 962.0	301.8 **At** 336.8	−71.15 **Rn** −61.85
27.00 **Fr** 676.8	699.8 **Ra** 1140	1050 **Ac** ‡ 3200															

†	795 **Ce** 3433	935 **Pr** 3510	1024 **Nd** 3074	1042 **Pm** (2730)	1072 **Sm** 1791	826 **Eu** 1596	1313 **Gd** 3273	1360 **Tb** 3230	1410 **Dy** 2567	1472 **Ho** 2694	1529 **Er** 2900	1545 **Tm** 1950	824 **Yb** 1194	1663 **Lu** 3402
‡	1750 **Th** 4788	1572 **Pa** (4000)	1135 **U** 3818	637 **Np** (3900)	640 **Pu** 3230	1176 **Am** (2067)	1340 **Cm** 3110	986 **Bk** (2623)	900 **Cf**	(860) **Es**	**Fm**	827 **Md**	**No**	**Lr**

9. First ionization energy, electron affinity and electronegativity of the elements

1312 −73 **H** 2.2																	2372 **He**
520 −60 **Li** 1.0	900 **Be** 1.6											801 −27 **B** 2.0	1086 −122 **C** 2.6	1402 **N** 3.0	1314 −141 (+753) **O** 3.4	1681 −328 **F** 4.0	2081 **Ne**
496 −53 **Na** 0.9	738 **Mg** 1.3											578 −42 **Al** 1.6	787 −134 **Si** 1.9	1012 −72 **P** 2.2	1000 −200 (+545) **S** 2.6	1251 −349 **Cl** 3.2	1520 **Ar**
419 −48 **K** 0.8	590 −2 **Ca** 1.0	633 −18 **Sc** 1.4	659 −8 **Ti** 1.5	651 −51 **V** 1.6	653 −64 **Cr** 1.7	717 **Mn** 1.6	762 −15 **Fe** 1.8	760 −64 **Co** 1.9	737 −112 **Ni** 1.9	745 −119 **Cu** 1.9	906 **Zn** 1.6	579 −41 **Ga** 1.8	762 −119 **Ge** 2.0	944 −78 **As** 2.2	941 −195 **Se** 2.6	1140 −325 **Br** 3.0	1351 **Kr**
403 −47 **Rb** 0.8	549 −5 **Sr** 1.0	600 −30 **Y** 1.2	640 −41 **Zr** 1.3	652 −88 **Nb** 1.6	684 −72 **Mo** 2.2	702 −53 **Tc** 2.1	710 −101 **Ru** 2.2	720 −110 **Rh** 2.3	804 −54 **Pd** 2.2	731 −126 **Ag** 1.9	868 **Cd** 1.7	558 −29 **In** 1.8	709 −107 **Sn** 2.0	831 −101 **Sb** 2.0	869 −190 **Te** 2.1	1008 −295 **I** 2.7	1170 **Xe**
376 −46 **Cs** 0.8	503 −14 **Ba** 0.9	538 −45 **La †** 1.1	659 −1 **Hf** 1.3	728 −31 **Ta** 1.5	759 −79 **W** 1.7	756 −14 **Re** 1.9	814 −106 **Os** 2.2	865 −151 **Ir** 2.2	864 −205 **Pt** 2.2	890 −223 **Au** 2.4	1007 **Hg** 1.9	589 −36 **Tl** 1.8	716 −35 **Pb** 1.8	703 −91 **Bi** 1.9	812 −183 **Po** 2.0	−270 **At** 2.2	1037 **Rn**
393 −47 **Fr** 0.7	509 −10 **Ra** 0.9	499 −34 **Ac ‡** 1.1															

First ionization energy / kJ mol^{-1} | Electron affinity (EA) / kJ mol^{-1} (2nd EA / kJ mol^{-1})

Element

Electronegativity

†	534 −63 **Ce** 1.1	528 −93 **Pr** 1.1	533 −185 **Nd** 1.1	539 **Pm**	545 **Sm** 1.2	547 −83 **Eu**	593 **Gd** 1.2	566 −112 **Tb**	573 < 0 **Dy** 1.2	581 **Ho** 1.2	589 **Er** 1.2	597 −99 **Tm** 1.3	603 2 **Yb**	524 −33 **Lu** 1.0
‡	609 **Th** 1.3	568 **Pa** 1.5	598 **U** 1.7	605 **Np** 1.3	581 **Pu** 1.3	576 **Am**	578 **Cm**	598 **Bk**	606 **Cf**	619 **Es**	627 **Fm**	635 **Md**	642 **No**	473 **Lr**

10. Atomic and ionic radii of the elements

The values for atomic radii used in this table are the covalent radii of the elements.

32 **H**					Atomic radius / 10^{-12} m **Element** Ionic radius / 10^{-12} m (charge)											37 **He**
130 **Li** 76 (1+)	99 **Be** 45 (2+)											84 **B** 27 (3+)	75 **C** 16 (4+)	71 **N** 146 (3−)	64 **O** 140 (2−)	60 **F** 133 (1−)	62 **Ne**
160 **Na** 102 (1+)	140 **Mg** 72 (2+)											124 **Al** 54 (3+)	114 **Si** 40 (4+)	109 **P** 38 (5+)	104 **S** 184 (2−)	100 **Cl** 181 (1−)	101 **Ar**
200 **K** 138 (1+)	174 **Ca** 100 (2+)	159 **Sc** 75 (3+)	148 **Ti** 86 (2+) 61 (4+)	144 **V** 79 (2+) 54 (5+)	130 **Cr** 62 (3+) 44 (6+)	129 **Mn** 83 (2+) 53 (4+)	124 **Fe** 61 (2+) 55 (3+)	118 **Co** 65 (2+) 55 (3+)	117 **Ni** 69 (2+)	122 **Cu** 77 (1+) 73 (2+)	120 **Zn** 74 (2+)	123 **Ga** 62 (3+)	120 **Ge** 53 (4+) 272 (4−)	120 **As** 58 (3+) 46 (5+)	118 **Se** 198 (2−)	117 **Br** 196 (1−)	116 **Kr**
215 **Rb** 152 (1+)	190 **Sr** 118 (2+)	176 **Y** 90 (3+)	164 **Zr** 72 (4+)	156 **Nb** 72 (3+) 64 (5+)	146 **Mo** 65 (4+)	138 **Tc** 65 (4+)	136 **Ru** 68 (3+) 62 (4+)	134 **Rh** 67 (3+) 60 (4+)	130 **Pd** 86 (2+) 62 (4+)	136 **Ag** 115 (1+)	140 **Cd** 95 (2+)	142 **In** 80 (+3)	140 **Sn** 118 (2+) 69 (4+)	140 **Sb** 76 (3+)	137 **Te** 221 (2−)	136 **I** 220 (1−)	136 **Xe**
238 **Cs** 167 (1+)	206 **Ba** 135 (2+)	194 **La** † 103 (3+)	164 **Hf** 71 (4+)	158 **Ta** 64 (5+)	150 **W** 66 (4+) 60 (6+)	141 **Re** 63 (4+) 53 (7+)	136 **Os** 63 (4+) 55 (6+)	132 **Ir** 68 (3+) 63 (4+)	130 **Pt** 80 (2+) 63 (4+)	130 **Au** 137 (1+) 85 (3+)	132 **Hg** 119 (1+) 102 (2+)	144 **Tl** 150 (1+) 89 (3+)	145 **Pb** 119 (2+) 78 (4+)	150 **Bi** 103 (3+) 76 (5+)	142 **Po** 97 (4+)	148 **At**	146 **Rn**
242 **Fr**	211 **Ra**	201 **Ac** ‡															

†	184 **Ce** 101 (3+) 87 (4+)	190 **Pr** 99 (3+) 85 (4+)	188 **Nd** 98 (3+)	186 **Pm** 97 (3+)	185 **Sm** 96 (3+)	183 **Eu** 117 (2+) 95 (3+)	182 **Gd** 94 (3+)	181 **Tb** 92 (3+) 76 (4+)	180 **Dy** 91 (3+)	179 **Ho** 90 (+3)	177 **Er** 89 (3+)	177 **Tm** 88 (3+)	178 **Yb** 87 (3+)	174 **Lu** 86 (3+)
‡	190 **Th** 94 (4+)	184 **Pa** 104 (3+) 90 (4+)	183 **U** 89 (4+) 73 (6+)	180 **Np** 101 (3+) 87 (4+)	180 **Pu** 100 (3+) 86 (4+)	173 **Am** 98 (3+) 85 (4+)	168 **Cm** 97 (3+)	168 **Bk** 96 (3+)	168 **Cf** 95 (3+)	165 **Es**	167 **Fm**	173 **Md**	176 **No** 110 (2+)	161 **Lr**

11. Covalent or average covalent bond lengths

Single bonds

Bond	Length / 10^{-12} m	Bond	Length / 10^{-12} m	Bond	Length / 10^{-12} m	Bond	Length / 10^{-12} m
H — H	74	N — H	101	Si — H	148	S — H	134
H — F	92	N — N	146	Si — Si	232	S — S	205
H — Cl	128	N — O	136	Si — S	215	S — F	158
H — Br	141	N — Si	174	Si — F	156	S — Cl	199
H — I	160	N — S	175	Si — Cl	202	S — Br	227
		N — F	136	Si — Br	216		
C — H	108	N — Cl	197	Si — I	243	F — F	142
C — C	154	N — Br	214			F — Cl	163
C — N	147			P — H	142	F — Br	176
C — O	143	O — H	97	P — P	221	F — I	257
C — Si	185	O — O	148	P — S	210		
C — P	184	O — Si	163	P — F	154	Cl — Cl	199
C — S	182	O — P	154	P — Cl	203	Cl — Br	214
C — F	138	O — S	161	P — Br	220	Cl — I	232
C — Cl	177	O — F	142	P — I	247		
C — Br	194	O — Cl	170			Br — Br	228
C — I	214					Br — I	247
						I — I	267

Multiple bonds

Bond	Length / 10^{-12} m	Bond	Length / 10^{-12} m	Bond	Length / 10^{-12} m
C = C	134	N = N	125	O = O	121
C = N	130	N = O	114	O = S	143
C = O	122				
C = S	156			S = S	189
C ≡ C	120	N ≡ N	110		
C ≡ N	116				
C ≡ O	113				

12. Bond enthalpies or average bond enthalpies at 298.15 K

Single bonds

Bond	Enthalpy / kJ mol^{-1}	Bond	Enthalpy / kJ mol^{-1}	Bond	Enthalpy / kJ mol^{-1}	Bond	Enthalpy / kJ mol^{-1}
H — H	436	N — H	391	Si — H	323	S — H	364
H — F	567	N — N	158	Si — Si	226	S — S	266
H — Cl	431	N — O	214	Si — S	293	S — F	327
H — Br	366	N — F	278	Si — F	597	S — Cl	271
H — I	298	N — Cl	192	Si — Cl	400	S — Br	218
				Si — Br	330		
C — H	414	O — H	463	Si — I	234	F — F	159
C — C	346	O — O	144			F — Cl	255
C — N	286	O — Si	466	P — H	322	F — Br	249
C — O	358	O — P	363	P — P	198	F — I	280
C — Si	307	O — F	191	P — F	490		
C — P	264	O — Cl	206	P — Cl	322	Cl — Cl	242
C — S	289	O — Br	201	P — Br	264	Cl — Br	219
C — F	492	O — I	201	P — I	184	Cl — I	211
C — Cl	324						
C — Br	285					Br — Br	193
C — I	228					Br — I	178
						I — I	151

Multiple bonds

Bond	Enthalpy / kJ mol^{-1}	Bond	Enthalpy / kJ mol^{-1}	Bond	Enthalpy / kJ mol^{-1}
C = C	614	N = N	470	O = O	498
C = N	615	N = O	587	O = S	522
C = O	804				
C = S	536			S = S	429
C ≡ C	839	N ≡ N	945		
C ≡ N	890				
C ≡ O	1077				

13. Thermodynamic data (selected compounds)

Substance	Formula	State	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$\Delta G_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
methane	CH_4	g	−74	−50	+186
ethane	C_2H_6	g	−84	−32	+230
propane	C_3H_8	g	−105	−24	+270
butane	C_4H_{10}	g	−126	−17	+310
pentane	C_5H_{12}	l	−173		
hexane	C_6H_{14}	l	−199		
ethene	C_2H_4	g	+52	+68	+220
propene	C_3H_6	g	+20	+62	+267
but-1-ene	C_4H_8	g	+0.1	+71	+306
cis-but-2-ene	C_4H_8	g	−7	+66	+301
trans-but-2-ene	C_4H_8	g	−11	+63	+297
ethyne	C_2H_2	g	+228	+211	+201
propyne	C_3H_4	g	+185	+194	+248
buta-1,3-diene	C_4H_6	g	+110	+151	+279
cyclohexane	C_6H_{12}	l	−156		
benzene	C_6H_6	l	+49	+125	+173
methylbenzene	$C_6H_5CH_3$	l	+12		
ethylbenzene	$C_6H_5CH_2CH_3$	l	−12		
phenylethene	$C_6H_5CHCH_2$	l	+104		
chloromethane	CH_3Cl	g	−82	−58	+235
dichloromethane	CH_2Cl_2	l	−124		+178
trichloromethane	$CHCl_3$	l	−134	−74	+202
bromomethane	CH_3Br	g	−36	−26	+246
iodomethane	CH_3I	l	−14		+163
chloroethane	C_2H_5Cl	g	−137	−53	
bromoethane	C_2H_5Br	l	−90	−26	+199
chlorobenzene	C_6H_5Cl	l	+11		
methanol	CH_3OH	l	−239	−167	+127
ethanol	C_2H_5OH	l	−278	−175	+161
phenol	C_6H_5OH	s	−165		+144
methanal	$HCHO$	g	−109	−102	+219
ethanal	CH_3CHO	g	−166	−133	+264
propanone	$(CH_3)_2CO$	l	−248		+200
methanoic acid	$HCOOH$	l	−425	−361	+129
ethanoic acid	CH_3COOH	l	−484	−390	+160
benzoic acid	C_6H_5COOH	s	−385		+168
methylamine	CH_3NH_2	g	−23	+32	+243
water	H_2O	l	−286	−237	+70
steam	H_2O	g	−242	−229	+189
carbon monoxide	CO	g	−111	−137	+198
carbon dioxide	CO_2	g	−394	−394	+214
hydrogen bromide	HBr	g	−36	−53	+199
hydrogen chloride	HCl	g	−92	−95	+187
hydrogen fluoride	HF	g	−273	−275	+174
hydrogen iodide	HI	g	+26	+2	+207

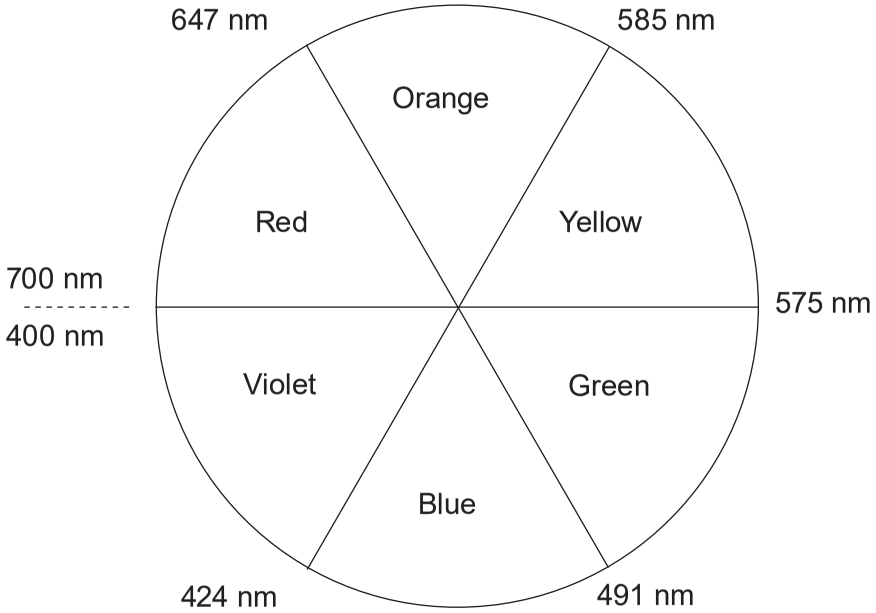
14. Enthalpies of combustion

The values of the molar enthalpy of combustion ($\Delta H_c^{\ominus}$) in the following table refer to a temperature of 298.15 K and a pressure of 100 kPa.

Substance	Formula	State	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
hydrogen	H_2	g	−286
sulfur	S	s	−297
carbon (graphite)	C	s	−394
carbon monoxide	CO	g	−283
methane	CH_4	g	−891
ethane	C_2H_6	g	−1561
propane	C_3H_8	g	−2219
butane	C_4H_{10}	g	−2878
pentane	C_5H_{12}	l	−3509
hexane	C_6H_{14}	l	−4163
octane	C_8H_{18}	l	−5470
cyclohexane	C_6H_{12}	l	−3920
ethene	C_2H_4	g	−1411
buta-1,3-diene	C_4H_6	g	−2541
ethyne	C_2H_2	g	−1301
benzene	C_6H_6	l	−3268
methylbenzene	$C_6H_5CH_3$	l	−3910
naphthalene	$C_{10}H_8$	s	−5156
chloroethane	C_2H_5Cl	g	−1413
iodoethane	C_2H_5I	l	−1463
trichloromethane	$CHCl_3$	l	−473
methanol	CH_3OH	l	−726
ethanol	C_2H_5OH	l	−1367

Substance	Formula	State	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
propan-1-ol	C_3H_7OH	l	−2021
butan-1-ol	C_4H_9OH	l	−2676
cyclohexanol	$C_6H_{11}OH$	s	−3728
phenol	C_6H_5OH	s	−3053
ethoxyethane	$(C_2H_5)_2O$	l	−2724
methanal	HCHO	g	−571
ethanal	CH_3CHO	g	−1167
benzaldehyde	C_6H_5CHO	l	−3525
propanone	$(CH_3)_2CO$	l	−1790
pentan-3-one	$(C_2H_5)_2CO$	l	−3100
phenylethanone	$CH_3COC_6H_5$	l	−4149
methanoic acid	HCOOH	l	−255
ethanoic acid	CH_3COOH	l	−874
benzoic acid	C_6H_5COOH	s	−3228
ethanedioic acid	$(COOH)_2$	s	−243
ethyl ethanoate	$CH_3COOC_2H_5$	l	−2238
ethanamide	CH_3CONH_2	s	−1186
methylamine	CH_3NH_2	g	−1086
phenylamine	$C_6H_5NH_2$	l	−3393
nitrobenzene	$C_6H_5NO_2$	l	−3088
urea	$CO(NH_2)_2$	s	−633
glucose	$C_6H_{12}O_6$	s	−2803
sucrose	$C_{12}H_{22}O_{11}$	s	−5640

15. Colour wheel with wavelengths of the visible spectrum



16. Lattice enthalpies at 298.15 K (experimental values)

The lattice enthalpy values ($\Delta H^{\ominus}_{\text{lattice}}$) in the following tables relate to the endothermic process $M_aX_b(s) \rightarrow aM^{b+}(g) + bX^{a-}(g)$ in which the gaseous ions of a crystal are separated to an infinite distance from each other.

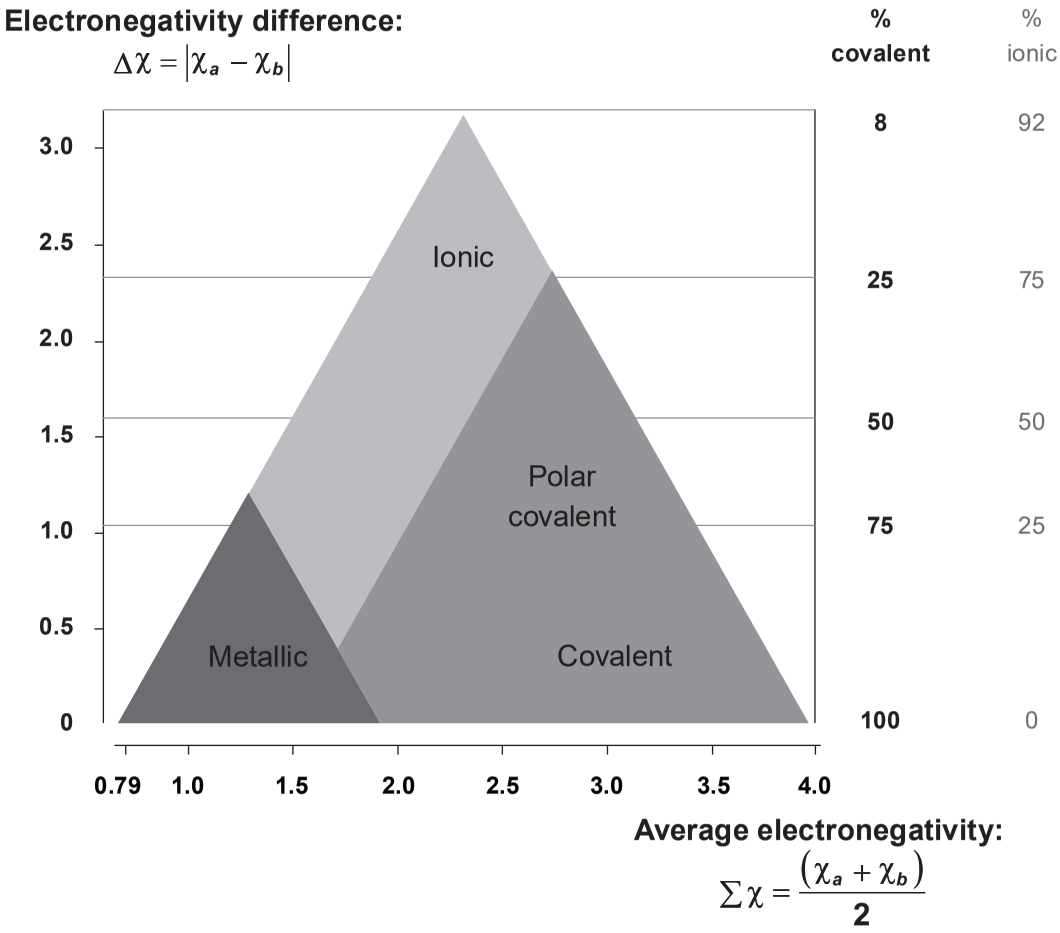
The data in these tables are experimental values obtained by means of a suitable Born–Haber cycle.

Alkali metal halides	$\Delta H^{\ominus}_{\text{lattice}}$ / kJ mol^{-1}			
	F	Cl	Br	I
Li	1049	864	820	764
Na	930	790	754	705
K	829	720	691	650
Rb	795	695	668	632
Cs	759	670	647	613

Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ / kJ mol^{-1}
CaF_2	2651
$BeCl_2$	3033
$MgCl_2$	2540
$CaCl_2$	2271
$SrCl_2$	2170
$BaCl_2$	2069
MgO	3791
CaO	3401

Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ / kJ mol^{-1}
SrO	3223
BaO	3054
$CuCl_2$	2824
AgF	974
AgCl	918
AgBr	905
AgI	892

17. Triangular bonding diagram (van Arkel–Ketelaar triangle)



18. Acid–base indicators

			Colour change	
Indicator	**pK_a**	**pH range**	**Acid**	**Alkali**
methyl orange	3.7	3.1–4.4	red	yellow
bromophenol blue	4.2	3.0–4.6	yellow	blue
bromocresol green	4.7	3.8–5.4	yellow	blue
methyl red	5.1	4.4–6.2	red	yellow
bromothymol blue	7.0	6.0–7.6	yellow	blue
phenol red	7.9	6.8–8.4	yellow	red
phenolphthalein	9.6	8.3–10.0	colourless	pink

19. Standard reduction potentials at 298.15 K

Oxidized species		Reduced species	$E^{\ominus}$ / V
$Li^+(aq) + e^-$	$\rightleftharpoons$	$Li(s)$	−3.04
$K^+(aq) + e^-$	$\rightleftharpoons$	$K(s)$	−2.93
$Ca^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Ca(s)$	−2.87
$Na^+(aq) + e^-$	$\rightleftharpoons$	$Na(s)$	−2.71
$Mg^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Mg(s)$	−2.37
$Al^{3+}(aq) + 3e^-$	$\rightleftharpoons$	$Al(s)$	−1.66
$Mn^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Mn(s)$	−1.18
$H_2O(l) + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-(aq)$	−0.83
$Zn^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Zn(s)$	−0.76
$Fe^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Fe(s)$	−0.45
$Ni^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Ni(s)$	−0.26
$Sn^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Sn(s)$	−0.14
$Pb^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Pb(s)$	−0.13
$H^+(aq) + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00
$Cu^{2+}(aq) + e^-$	$\rightleftharpoons$	$Cu^+(aq)$	+0.15
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$	$\rightleftharpoons$	$H_2SO_3(aq) + H_2O(l)$	+0.17
$Cu^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Cu(s)$	+0.34
$\frac{1}{2}O_2(g) + H_2O(l) + 2e^-$	$\rightleftharpoons$	$2OH^-(aq)$	+0.40
$Cu^+(aq) + e^-$	$\rightleftharpoons$	$Cu(s)$	+0.52
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	$I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^-$	$\rightleftharpoons$	$Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^-$	$\rightleftharpoons$	$Ag(s)$	+0.80
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	$Br^-(aq)$	+1.09
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^-$	$\rightleftharpoons$	$H_2O(l)$	+1.23
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	$\rightleftharpoons$	$2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	$Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^-$	$\rightleftharpoons$	$Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	$F^-(aq)$	+2.87

20. Infrared data

Characteristic ranges for infrared absorption due to stretching vibrations in organic molecules

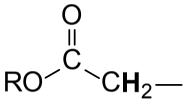
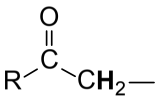
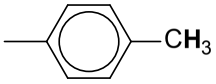
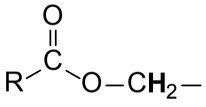
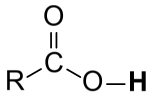
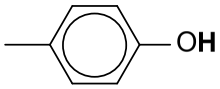
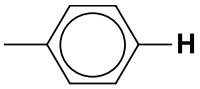
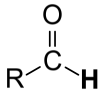
Bond	Types of organic molecules	Wavenumber / cm^{-1}	Intensity
C — I	iodoalkanes	490–620	strong
C — Br	bromoalkanes	500–600	strong
C — Cl	chloroalkanes	600–800	strong
C — F	fluoroalkanes	1000–1400	strong
C — O	alcohols, esters, ethers	1050–1410	strong
C = C	alkenes	1620–1680	medium-weak; multiple bands
C = O	aldehydes, ketones, carboxylic acids and esters	1700–1750	strong
C ≡ C	alkynes	2100–2260	variable
O — H	carboxylic acids (with hydrogen bonding)	2500–3000	strong, very broad
C — H	alkanes, alkenes, arenes	2850–3090	strong
O — H	alcohols and phenols (with hydrogen bonding)	3200–3600	strong, broad
N — H	primary amines	3300–3500	medium; two bands

21. ^{1}H NMR data

Typical proton chemical shift values (δ) relative to tetramethylsilane (TMS)

R represents an alkyl group, and Hal represents F, Cl, Br or I.

These values may vary for different solvents and conditions.

Type of proton	Chemical shift / ppm
—CH_3	0.9–1.0
—CH_2–R	1.3–1.4
—CHR_2	1.5
	2.0–2.5
	2.2–2.7
	2.5–3.5
—C≡C—H	1.8–3.1
—CH_2–Hal	3.5–4.4
R—O—CH_2—	3.3–3.7
	3.7–4.8
	9.0–13.0
R—O—H	1.0–6.0
—CH=CH_2	4.5–6.0
	4.0–12.0
	6.9–9.0
	9.4–10.0

22. Mass spectral fragments lost

Mass lost (M_r)	Possible neutral fragment lost
15	$\bullet CH_3$
17	$\bullet OH$
18	H_2O
28	$CH_2{=}CH_2$ CO
29	$\bullet CH_2CH_3$ $\bullet CHO$
31	$\bullet OCH_3$
45	$\bullet COOH$

23. References

Data in sections 7, 8, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20, 21 and 22 were taken fully or in part from:

Blackman, A., Gahan, L. R., Aylward, G. H., & Findlay, T. J. V. (2014). *Aylward and Findlay's SI Chemical Data*. (7th ed.). John Wiley & Sons.

National Institute of Standards and Technology. (2021). *NIST Chemistry WebBook SRD 69, NIST Standard Reference Database*. U.S. Department of Commerce. http://webbook.nist.gov

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Leach, M. R. (2021). *The Chemogenesis Web Book: Timeline of structural theory.* http://www.meta-synthesis.com/webbook/30_timeline/timeline.html