

STUDY EDITION

CHEMISTRY: DATA BOOKLET

The chemistry data booklet, annotated page for page: the same periodic table, the same physical constants and the same numerical data, on the same page numbers as the copy you are given.



First examination
2025

Scope

24 numbered sections plus the update log: equations, constants, the periodic table, element data, thermodynamic data, spectra and reference tables.

How to use it

Section order and page breaks match the original, so the page you revise here is the page you turn to there.

Printing

A4, scale 100%, background graphics on. One sheet prints as one page.

Annotated study edition — always sit the exam with the official booklet your school issues.

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INTRO INTRODUCTION

This booklet collects the chemical and physical data a Chemistry course leans on: the equations used in calculations, the constants and unit conversions those equations need, the periodic table and the element data behind it, and the thermodynamic, spectroscopic and acid–base tables used in practical work.

It is meant to be used, not memorized. The point of keeping it beside you for the whole course is that you stop spending working memory on the value of a constant or the colour of an indicator at pH 9, and spend it on the chemistry instead. Section 1 is the one worth knowing your way around: the “understandings” statements in the guide refer back to it.

Organization. Sections 1 to 5 are the working tools (equations, constants, multipliers, conversions and the electromagnetic spectrum). Sections 6 to 12 are element data. Sections 13 to 19 cover thermodynamics, bonding and electrochemistry. Sections 20 to 23 are the analytical tables — infrared, NMR, mass spectra and uncertainty propagation — and section 24 lists where the data came from.

In the examination. You are given a clean copy of the official booklet, and it is the only reference you may use. Practise with this one so that finding a value becomes muscle memory: the section numbers, the page breaks and the running foot all match, so page 14 here is page 14 there.

A note on the numbers. Values are quoted to the precision the source table gives, and rounded values are printed as rounded — use them as they stand, and let the uncertainty rules in section 23 decide how many figures an answer deserves. Atomic and ionic radii are quoted in 10^{-12} m, bond lengths in the same unit, and thermodynamic data at 298.15 K unless a heading says otherwise.

1 SOME RELEVANT EQUATIONS

QUANTITY	EQUATION
Speed of light from frequency and wavelength	$c = f\lambda$
Energy of a photon	$E = hf$
Amount of substance from mass	$n = \frac{m}{M}$
Amount of substance from concentration	$n = CV$
Ideal gas equation	$PV = nRT$
Combined gas equation	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
Heat energy from specific heat capacity	$Q = mc\Delta T$
Percentage atom economy	$\% \text{ atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100$
Enthalpy change from standard enthalpies of formation	$\Delta H^\circ = \Sigma(\Delta H_f^\circ \text{ products}) - \Sigma(\Delta H_f^\circ \text{ reactants})$
Enthalpy change from standard enthalpies of combustion	$\Delta H^\circ = \Sigma(\Delta H_c^\circ \text{ reactants}) - \Sigma(\Delta H_c^\circ \text{ products})$
Standard Gibbs energy change	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$
Gibbs energy change away from standard conditions	$\Delta G = \Delta G^\circ + RT \ln Q$
Standard Gibbs energy change and the equilibrium constant	$\Delta G^\circ = -RT \ln K$
Standard Gibbs energy change and cell potential	$\Delta G^\circ = -nFE^\circ$
Arrhenius equation, exponential form	$k = Ae^{\frac{-E_a}{RT}}$
Arrhenius equation, logarithmic form	$\ln k = \frac{-E_a}{RT} + \ln A$
pH of a solution (either form)	$\text{pH} = -\log_{10} [H_3O^+]$ $\text{pH} = -\log_{10} [H^+]$
Ionic product constant of water	$K_w = [H^+][OH^-]$
pOH of a solution	$\text{pOH} = -\log_{10} [OH^-]$

2 PHYSICAL CONSTANTS

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

3 METRIC (SI) MULTIPLIERS

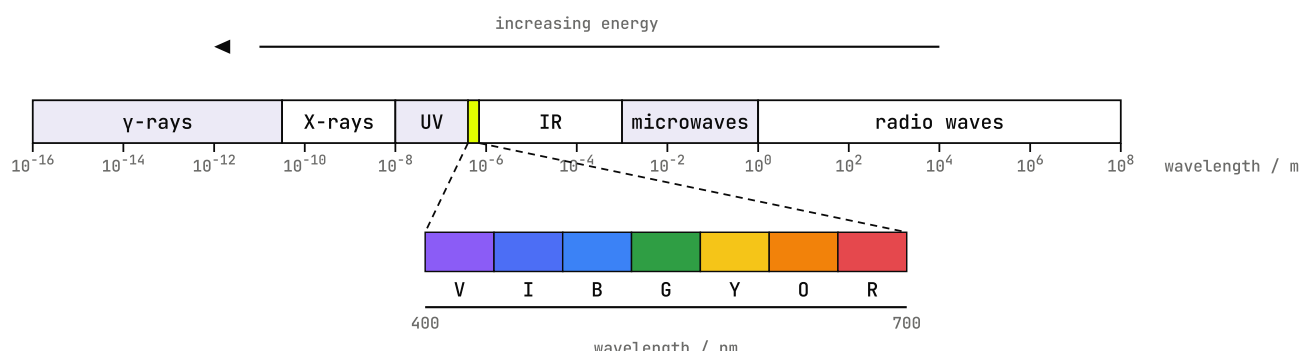
PREFIX	ABBREVIATION	VALUE
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^9
mega	M	10^6
kilo	k	10^3
hecto	h	10^2
deca	da	10^1
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Multiply the unit by the value: $1 \text{ km} = 1 \times 10^3 \text{ m}$, and $1 \text{ }\mu\text{m} = 1 \times 10^{-6} \text{ m}$. The prefix belongs to the unit it is written against, so cm^3 means $(10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3$, not 10^{-2} m^3 .

4 UNIT CONVERSIONS AND STANDARD CONDITIONS

QUANTITY	RELATIONSHIP
Temperature in kelvin	temperature (K) = temperature (°C) + 273.15
Volume	$1 \text{ dm}^3 = 1 \text{ litre} = 1 \times 10^{-3} \text{ m}^3 = 1 \times 10^3 \text{ cm}^3$
Standard temperature and pressure	STP: 273.15 K and 100 kPa
Standard ambient temperature and pressure	SATP: 298.15 K and 100 kPa

5 THE ELECTROMAGNETIC SPECTRUM



WAVELENGTH INCREASES TO THE RIGHT, ENERGY TO THE LEFT; THE VISIBLE WINDOW IS OPENED OUT BELOW THE AXIS.

6 NAMES OF THE ELEMENTS

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

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

Alphabetical by element name: actinium to lutetium on this page, magnesium to zirconium on the next. The Z column is the atomic number, so a name here leads straight to that element's data elsewhere in the booklet.

6 NAMES OF THE ELEMENTS (CONTINUED)

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

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

7 THE PERIODIC TABLE

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.01																	2 He 4.00
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
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
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
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
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)
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)			

ATOMIC NUMBER TOP LEFT SYMBOL CENTRE RELATIVE ATOMIC MASS BELOW † LANTHANIDES ‡ ACTINIDES

A mass in brackets is the mass number of the longest-lived isotope, not a standard atomic weight, because no stable isotope exists. The two detached rows hold the lanthanides (58–71) and the actinides (90–103); lanthanum and actinium stay in group 3, marked † and ‡. Values as printed on page 8 of the source booklet.

8

MELTING POINTS AND BOILING POINTS OF THE ELEMENTS AT 101.325 KPA

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
-259.2 H -252.9																	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			

MELTING POINT / °C ABOVE THE SYMBOL BOILING POINT / °C BELOW IT AT 101.325 KPA † LANTHANIDES ‡ ACTINIDES

An empty line means the source table records no value at that pressure: helium has no melting point at 101.325 kPa, so only its boiling point is printed, and no value is listed for francium to actinium beyond radium, nor for the elements past lawrencium.

9 FIRST IONIZATION ENERGY, ELECTRON AFFINITY AND ELECTRONEGATIVITY OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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															
	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

IE FIRST IONIZATION ENERGY / KJ MOL⁻¹ EA ELECTRON AFFINITY / KJ MOL⁻¹, SECOND ONE BRACKETED EN ELECTRONEGATIVITY BELOW THE SYMBOL † LANTHANIDES ‡ ACTINIDES

A blank line means the source table leaves that value empty; the noble gases have no electron affinity, beryllium and nitrogen have none either, and several of the heavier elements have no Pauling electronegativity. Dysprosium is printed as < 0 because its affinity is negative, and the source prints ytterbium's as 2.

10 ATOMIC AND IONIC RADII OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
32 H																	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			

ALL RADII IN 10⁻¹² m ATOMIC RADIUS ABOVE THE SYMBOL IONIC RADIUS AND CHARGE BELOW IT † LANTHANIDES ‡ ACTINIDES

The atomic radius used here is the covalent radius. An element with more than one common ion shows one line per charge, so iron reads 61 (2+) and 55 (3+). A blank line means the source lists no value, which is the case for the noble gases and for most of the elements past lawrencium.

11 COVALENT OR AVERAGE COVALENT BOND LENGTHS

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	191
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

DOUBLE 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

TRIPLE BONDS

BOND	LENGTH / 10^{-12} m	BOND	LENGTH / 10^{-12} m	BOND	LENGTH / 10^{-12} m
C≡C	120	N≡N	110		
C≡N	116				
C≡O	113				

Bond lengths in 10^{-12} m (picometres). Values are averages: the length of a bond varies a little with the compound it sits in, so a single figure stands for the usual case. Shorter bonds hold more energy.

12 BOND ENTHALPIES OR AVERAGE BOND ENTHALPIES AT 298.15 K

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

DOUBLE 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

TRIPLE BONDS

BOND	ENTHALPY / kJ mol^{-1}	BOND	ENTHALPY / kJ mol^{-1}	BOND	ENTHALPY / kJ mol^{-1}
C≡C	839	N≡N	945		
C≡N	890				
C≡O	1077				

Enthalpy in kJ mol^{-1} at 298.15 K: the energy needed to break one mole of the bond with everything in the gas phase. The values are averages over the compounds that contain the bond, which is what makes them usable in a Hess cycle estimate.

13 THERMODYNAMIC DATA (SELECTED COMPOUNDS)

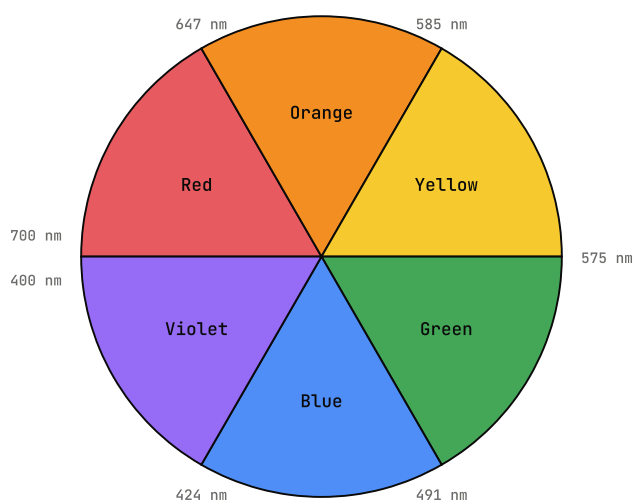
SUBSTANCE	FORMULA	STATE	$\Delta H_f^\circ / \text{kJ mol}^{-1}$	$\Delta G_f^\circ / \text{kJ mol}^{-1}$	$S^\circ / \text{J K}^{-1} \text{mol}^{-1}$
methane	CH ₄	g	-74	-50	+186
ethane	C ₂ H ₆	g	-84	-32	+230
propane	C ₃ H ₈	g	-105	-24	+270
butane	C ₄ H ₁₀	g	-126	-17	+310
pentane	C ₅ H ₁₂	l	-173	—	—
hexane	C ₆ H ₁₄	l	-199	—	—
ethene	C ₂ H ₄	g	+52	+68	+220
propene	C ₃ H ₆	g	+20	+62	+267
but-1-ene	C ₄ H ₈	g	+0.1	+71	+306
cis-but-2-ene	C ₄ H ₈	g	-7	+66	+301
trans-but-2-ene	C ₄ H ₈	g	-11	+63	+297
ethyne	C ₂ H ₂	g	+228	+211	+201
propyne	C ₃ H ₄	g	+185	+194	+248
buta-1,3-diene	C ₄ H ₆	g	+110	+151	+279
cyclohexane	C ₆ H ₁₂	l	-156	—	—
benzene	C ₆ H ₆	l	+49	+125	+173
methylbenzene	C ₆ H ₅ CH ₃	l	+12	—	—
ethylbenzene	C ₆ H ₅ CH ₂ CH ₃	l	-12	—	—
phenylethene	C ₆ H ₅ CHCH ₂	l	+104	—	—
chloromethane	CH ₃ Cl	g	-82	-58	+235
dichloromethane	CH ₂ Cl ₂	l	-124	—	+178
trichloromethane	CHCl ₃	l	-134	-74	+202
bromomethane	CH ₃ Br	g	-36	-26	+246
iodomethane	CH ₃ I	l	-14	—	+163
chloroethane	C ₂ H ₅ Cl	g	-137	-53	—
bromoethane	C ₂ H ₅ Br	l	-90	-26	+199
chlorobenzene	C ₆ H ₅ Cl	l	+11	—	—
methanol	CH ₃ OH	l	-239	-167	+127
ethanol	C ₂ H ₅ OH	l	-278	-175	+161
phenol	C ₆ H ₅ OH	s	-165	—	+144
methanal	HCHO	g	-109	-102	+219
ethanal	CH ₃ CHO	g	-166	-133	+264
propanone	(CH ₃) ₂ CO	l	-248	—	+200
methanoic acid	HCOOH	l	-425	-361	+129
ethanoic acid	CH ₃ COOH	l	-484	-390	+160
benzoic acid	C ₆ H ₅ COOH	s	-385	—	+168
methylamine	CH ₃ NH ₂	g	-23	+32	+243
water	H ₂ O	l	-286	-237	+70
steam	H ₂ O	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

Standard enthalpies and Gibbs energies of formation and standard molar entropies at 298.15 K. A dash means the source table gives no value. Elements in their standard states are the zero of the enthalpy and Gibbs energy scales.

14 ENTHALPIES OF COMBUSTION

Standard molar enthalpy of combustion at 298.15 K and 100 kPa; the enthalpy change when one mole of the substance burns completely in oxygen, so every value is negative.

SUBSTANCE	FORMULA	STATE	$\Delta H_c^\circ / \text{kJ mol}^{-1}$	SUBSTANCE	FORMULA	STATE	$\Delta H_c^\circ / \text{kJ mol}^{-1}$
hydrogen	H ₂	g	-286	propan-1-ol	C ₃ H ₇ OH	l	-2021
sulfur	S	s	-297	butan-1-ol	C ₄ H ₉ OH	l	-2676
carbon (graphite)	C	s	-394	cyclohexanol	C ₆ H ₁₁ OH	s	-3728
carbon monoxide	CO	g	-283	phenol	C ₆ H ₅ OH	s	-3053
methane	CH ₄	g	-891	ethoxyethane	(C ₂ H ₅) ₂ O	l	-2724
ethane	C ₂ H ₆	g	-1561	methanal	HCHO	g	-571
propane	C ₃ H ₈	g	-2219	ethanal	CH ₃ CHO	g	-1167
butane	C ₄ H ₁₀	g	-2878	benzaldehyde	C ₆ H ₅ CHO	l	-3525
pentane	C ₅ H ₁₂	l	-3509	propanone	(CH ₃) ₂ CO	l	-1790
hexane	C ₆ H ₁₄	l	-4163	pentan-3-one	(C ₂ H ₅) ₂ CO	l	-3100
octane	C ₈ H ₁₈	l	-5470	phenylethanone	CH ₃ COC ₆ H ₅	l	-4149
cyclohexane	C ₆ H ₁₂	l	-3920	methanoic acid	HCOOH	l	-255
ethene	C ₂ H ₄	g	-1411	ethanoic acid	CH ₃ COOH	l	-874
buta-1,3-diene	C ₄ H ₆	g	-2541	benzoic acid	C ₆ H ₅ COOH	s	-3228
ethyne	C ₂ H ₂	g	-1301	ethanedioic acid	(COOH) ₂	s	-243
benzene	C ₆ H ₆	l	-3268	ethyl ethanoate	CH ₃ COOC ₂ H ₅	l	-2238
methylbenzene	C ₆ H ₅ CH ₃	l	-3910	ethanamide	CH ₃ CONH ₂	s	-1186
naphthalene	C ₁₀ H ₈	s	-5156	methylamine	CH ₃ NH ₂	g	-1086
chloroethane	C ₂ H ₅ Cl	g	-1413	phenylamine	C ₆ H ₅ NH ₂	l	-3393
iodoethane	C ₂ H ₅ I	l	-1463	nitrobenzene	C ₆ H ₅ NO ₂	l	-3088
trichloromethane	CHCl ₃	l	-473	urea	CO(NH ₂) ₂	s	-633
methanol	CH ₃ OH	l	-726	glucose	C ₆ H ₁₂ O ₆	s	-2803
ethanol	C ₂ H ₅ OH	l	-1367	sucrose	C ₁₂ H ₂₂ O ₁₁	s	-5640

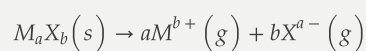
15 COLOUR WHEEL WITH WAVELENGTHS OF THE VISIBLE SPECTRUM

COLOUR	WAVELENGTH
Red	647–700 nm
Orange	585–647 nm
Yellow	575–585 nm
Green	491–575 nm
Blue	424–491 nm
Violet	400–424 nm

Each boundary is a wavelength where the eye stops calling one colour by its old name. The wheel is continuous: 400 nm and 700 nm meet on the left, so red at 700 nm is next to violet at 400 nm.

16 LATTICE ENTHALPIES AT 298.15 K (EXPERIMENTAL VALUES)

The lattice enthalpy is the energy needed to pull one mole of an ionic solid apart into gaseous ions at an infinite separation, so the process is endothermic and the values are positive. All of them were obtained experimentally, through a Born–Haber cycle.



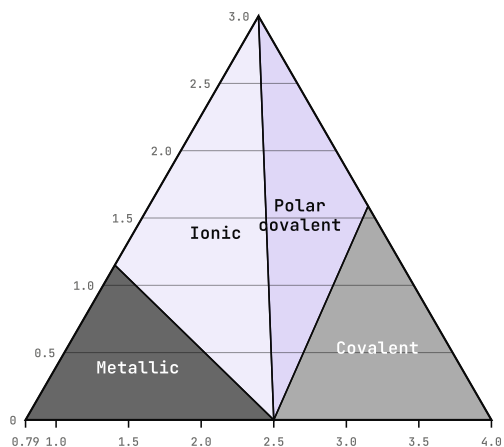
ALKALI METAL HALIDES • KJ MOL⁻¹

	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 • KJ MOL⁻¹

COMPOUND	$\Delta H_{\text{lattice}}^\circ / \text{kJ mol}^{-1}$	COMPOUND	$\Delta H_{\text{lattice}}^\circ / \text{kJ mol}^{-1}$
CaF ₂	2651	SrO	3223
BeCl ₂	3033	BaO	3054
MgCl ₂	2540	CuCl ₂	2824
CaCl ₂	2271	AgF	974
SrCl ₂	2170	AgCl	918
BaCl ₂	2069	AgBr	905
MgO	3791	AgI	892
CaO	3401		

17 TRIANGULAR BONDING DIAGRAM (VAN ARKEL–KETELAAR TRIANGLE)



ELECTRONEGATIVITY DIFFERENCE

$$\Delta\chi = |\chi_a - \chi_b|$$

AVERAGE ELECTRONEGATIVITY

$$\Sigma\chi = \frac{(\chi_a + \chi_b)}{2}$$

IONIC CHARACTER

$\Delta\chi$	% COVALENT	% IONIC
3.0	8	92
2.5	25	75
2.0	50	50
1.0	75	25
0	100	0

Plot a compound by its electronegativity difference against the average electronegativity of the two atoms. Bottom left, where the atoms are alike and both weakly electronegative, bonding is metallic; bottom right, where they are alike but strongly electronegative, it is covalent; the further up the triangle, the more the difference in electronegativity pushes the bond towards ionic. The boundaries are guides, not fences.

18 ACID-BASE INDICATORS

INDICATOR	pK_a	PH RANGE	COLOUR IN ACID	COLOUR IN 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	4.0–5.6	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	6.4–8.0	yellow	red
phenolphthalein	9.6	8.0–10.0	colourless	pink

The pH range is where the indicator is changing colour, so it is the range over which it is useful for a titration. Pick one whose range straddles the pH at the equivalence point, and remember that the colour you see is the one the indicator has on the far side of the range.

19 STANDARD REDUCTION POTENTIALS AT 298.15 K

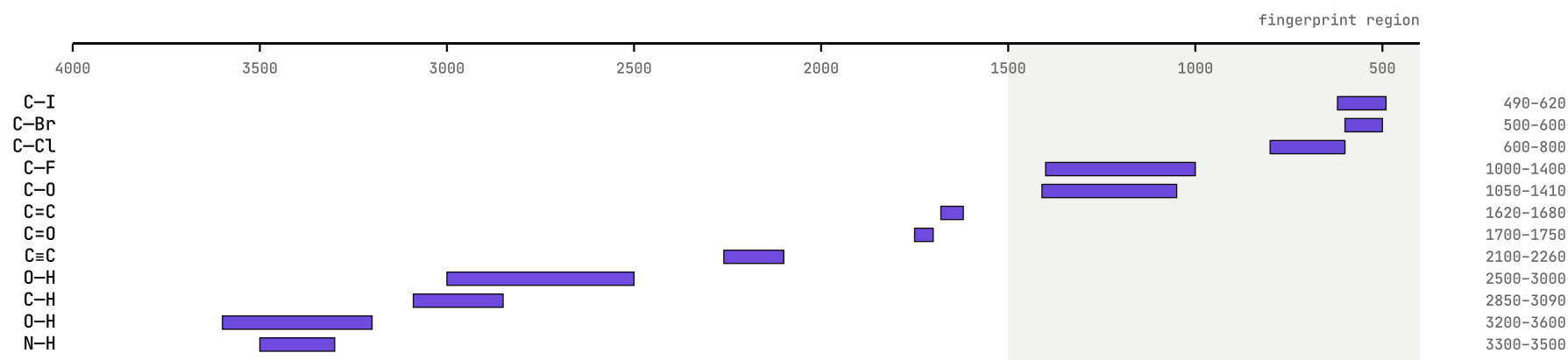
OXIDIZED SPECIES	REDUCED SPECIES	E° / V
$Li^+(aq) + e^-$	$Li(s)$	-3.04
$K^+(aq) + e^-$	$K(s)$	-2.93
$Ca^{2+}(aq) + 2e^-$	$Ca(s)$	-2.87
$Na^+(aq) + e^-$	$Na(s)$	-2.71
$Mg^{2+}(aq) + 2e^-$	$Mg(s)$	-2.37
$Al^{3+}(aq) + 3e^-$	$Al(s)$	-1.66
$Mn^{2+}(aq) + 2e^-$	$Mn(s)$	-1.18
$H_2O(l) + e^-$	$\frac{1}{2}H_2(g)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

Each line is a reduction half-equation and its standard electrode potential against the hydrogen electrode, in volts, at 298.15 K with all species at unit activity. A more positive potential means the left-hand species takes electrons more readily, so it oxidizes the species below it.

20 INFRARED DATA

Characteristic stretching ranges for organic molecules; below 1500 cm^{-1} the fingerprint region identifies the whole molecule rather than a single bond.

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
$\text{C}\equiv\text{C}$	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



WAVENUMBER / cm^{-1} DECREASING TO THE RIGHT; EACH BAR IS ONE OF THE RANGES ABOVE, DRAWN TO SCALE, AND THE SHADED ZONE IS THE FINGERPRINT REGION.

21 ^1H NMR DATA

Typical proton chemical shifts, δ , in ppm downfield from tetramethylsilane (TMS). **R** is an alkyl group, **Hal** is F, Cl, Br or I, and *arene* stands for an aromatic ring. Solvent, concentration and hydrogen bonding all move a shift a little, which is why the table gives ranges.

TYPE OF PROTON	CHEMICAL SHIFT / ppm
$-\text{CH}_3$	0.9–1.0
$-\text{CH}_2-\text{R}$	1.3–1.4
$-\text{CHR}_2$	1.5
$\text{RO}-\text{C}(=\text{O})-\text{CH}_2-$	2.0–2.5
$\text{R}-\text{C}(=\text{O})-\text{CH}_2-$	2.2–2.7
<i>arene</i> $-\text{CH}_3$	2.5–3.5
$-\text{C}\equiv\text{C}-\text{H}$	1.8–3.1
$-\text{CH}_2-\text{Hal}$	3.5–4.4
$\text{R}-\text{O}-\text{CH}_2-$	3.3–3.7
$\text{R}-\text{C}(=\text{O})-\text{O}-\text{CH}_2-$	3.7–4.8
$\text{R}-\text{C}(=\text{O})-\text{O}-\text{H}$	9.0–13.0
$\text{R}-\text{O}-\text{H}$	1.0–6.0
$-\text{CH}=\text{CH}_2$	4.5–6.0
<i>arene</i> $-\text{OH}$	4.0–12.0
<i>arene</i> $-\text{H}$	6.9–9.0
$\text{R}-\text{C}(=\text{O})-\text{H}$	9.4–10.0

22 MASS SPECTRAL FRAGMENTS LOST

MASS LOST (M_r)	POSSIBLE NEUTRAL FRAGMENT LOST
15	• CH_3
17	• OH
18	H_2O
28	$CH_2 = CH_2$ CO
29	• CH_2CH_3 • CHO
31	• OCH_3
45	• $COOH$

23 UNCERTAINTIES

IF	THEN
$y = a \pm b$	$\Delta y = \Delta a + \Delta b$
$y = \frac{ab}{c}$	$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$
$y = a^n$	$\frac{\Delta y}{y} = \left n \frac{\Delta a}{a} \right $

The same rules written out: absolute uncertainties add when quantities are added or subtracted, fractional uncertainties add when they are multiplied or divided, and a power multiplies the fractional uncertainty by the power. Quote the result to the same number of decimal places, or the same number of significant figures, as the least precise measurement in it.

24 REFERENCES

The data in sections 7 to 14 and 16 to 22 come, wholly or in part, from the reference works below. The triangular bonding diagram in section 17 follows the treatment published by the author named last. These are the citations as the source booklet gives them.

- [1] 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.
- [2] 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>
- [3] Rumble, J. R. (Ed.). (2019). *CRC Handbook of Chemistry and Physics* (100th ed.). CRC Press.
- [4] Leach, M. R. (2021). *The Chemogenesis Web Book: Timeline of structural theory*. http://www.metasynthesis.com/webbook/30_timeline/timeline.html

On the numbers. Reference works revise their values between editions. Where a value matters to a calculation, the precision printed here is the precision to use, and the uncertainty rules in section 23 decide how many figures the answer keeps.

LOG UPDATES TO THE PUBLICATION

What changed in the source booklet over the two years before this edition, most recent first. Spelling and typographic corrections are not listed, and this page carries the same changes so that a value you remember from an older printing can be checked.

FEBRUARY 2024

11. Covalent or average covalent bond lengths. The F–I bond length was corrected to 191×10^{-12} m, which is the value printed in section 11 on page 12 of this copy.

18. Acid–base indicators. The pH ranges for bromocresol green, phenol red and phenolphthalein were updated to the latest published data. Section 18 on page 19 carries the revised ranges: 4.0–5.6, 6.4–8.0 and 8.0–10.0.

23. Uncertainties. This section, setting out how uncertainties propagate through sums, products and powers, was added. It is on page 23, below the mass spectral fragment table.

If you are working from an older printing, check these three sections first: they are the ones where a number is most likely to differ from the copy in front of you.