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Chemistry

Equations, constants, the periodic table and reference data

SL HL

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PART 1

Equations

S1.4 **Amount of substance**	$n = \frac{m}{M} = cV$ n = amount (mol), m = mass (g), M = molar mass (g mol^{-1}), c = concentration (mol dm^{-3}), V = volume of solution (dm^3)
S1.5 **Ideal gas equation**	$PV = nRT$ P = pressure (Pa), V = volume (m^3), T = absolute temperature (K)
S1.5 **Combined gas law (fixed amount of gas)**	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
S1.3 HL **Speed and energy of light**	$c = f\lambda \qquad E = hf$ c = speed of light (m s^{-1}), f = frequency (s^{-1}), λ = wavelength (m), E = energy of one photon (J), h = Planck constant (J s)
R1.1 **Heat transferred to or from a substance**	$Q = mc\Delta T$ Q = heat (J), m = mass (g), c = specific heat capacity (J g^{-1} K^{-1}), ΔT = temperature change (K)
R1.2 HL **Standard enthalpy change from formation or combustion data**	$\Delta H^\ominus = \sum \Delta H_f^\ominus(\text{products}) - \sum \Delta H_f^\ominus(\text{reactants})$ $\Delta H^\ominus = \sum \Delta H_c^\ominus(\text{reactants}) - \sum \Delta H_c^\ominus(\text{products})$ all values in kJ mol^{-1}

R1.4

Gibbs energy change

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

$\Delta G^{\ominus}$, $\Delta H^{\ominus}$ in kJ mol^{-1}; $\Delta S^{\ominus}$ in J K^{-1} mol^{-1} (divide by 1000 before combining); T in K

R2.1

Atom economy

$$\%\ \text{atom economy} = \frac{\text{mass of desired product}}{\text{total mass of all reactants}} \times 100$$

HL

R2.2

Arrhenius equation

$$k = A\mathrm{e}^{-E_a/RT} \qquad \ln k = -\frac{E_a}{RT} + \ln A$$

k = rate constant, A = Arrhenius (pre-exponential) factor, E_a = activation energy (J mol^{-1}), R = gas constant (J K^{-1} mol^{-1})

HL

R2.3

Gibbs energy and equilibrium

$$\Delta G^{\ominus} = -RT\ln K \qquad \Delta G = \Delta G^{\ominus} + RT\ln Q$$

K = equilibrium constant, Q = reaction quotient

R3.1

pH and the ionic product of water

$$\mathrm{pH} = -\log_{10}[\mathrm{H_3O^+}] \ \text{ or } \ \mathrm{pH} = -\log_{10}[\mathrm{H^+}] \qquad K_w = [\mathrm{H^+}][\mathrm{OH^-}]$$

HL

R3.1

pOH

$$\mathrm{pOH} = -\log_{10}[\mathrm{OH^-}]$$

HL

R3.2

Gibbs energy and cell potential

$$\Delta G^{\ominus} = -nFE^{\ominus}$$

$\Delta G^{\ominus}$ in J, n = moles of electrons transferred, F = Faraday constant (C mol^{-1}), $E^{\ominus}$ = standard cell potential (V)

Propagating uncertainties

$$y = a \pm b \Rightarrow \Delta y = \Delta a + \Delta b \qquad y = \frac{ab}{c} \Rightarrow \frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$

$$y = a^n \Rightarrow \frac{\Delta y}{y} = \left| n\frac{\Delta a}{a} \right|$$

PART 2

Constants, units and the electromagnetic spectrum

Fundamental constants

Quantity	Symbol	Value
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	$22.7\ \text{dm}^3\ \text{mol}^{-1}$
Speed of light	c	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Specific heat capacity of water	c_w	$4.18\ \text{J g}^{-1}\ \text{K}^{-1} = 4.18\ \text{kJ kg}^{-1}\ \text{K}^{-1}$
Planck constant	h	$6.63 \times 10^{-34}\ \text{J s}$
Faraday constant	F	$9.65 \times 10^{4}\ \text{C mol}^{-1}$
Ionic product of water (298 K)	K_w	$1.00 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$
Proton rest mass	m_p	$1.672622 \times 10^{-27}\ \text{kg}$
Neutron rest mass	m_n	$1.674927 \times 10^{-27}\ \text{kg}$
Electron rest mass	m_e	$9.109384 \times 10^{-31}\ \text{kg}$
Elementary charge	e	$1.602177 \times 10^{-19}\ \text{C}$

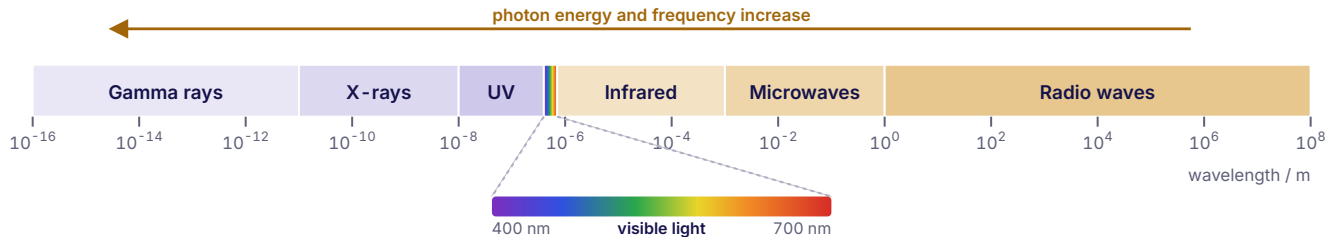
Unit conversions and standard conditions

Quantity	Value
Volume	$1\ \text{dm}^3 = 1\ \text{L} = 10^{-3}\ \text{m}^3 = 10^{3}\ \text{cm}^3$
Temperature	$T(\text{K}) = \theta(^\circ\text{C}) + 273.15$
STP	273.15 K and 100 kPa
SATP	298.15 K and 100 kPa

Metric (SI) prefixes

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

The electromagnetic spectrum



PART 3

The periodic table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1 H 1.01																2
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	1
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	1
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	3
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	5
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)	8
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)	1
	57–71 La–Lu			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	
	89–103 Ac–Lr			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
Symbol
Relative atomic mass
Values in brackets: mass number of the most stable isotope.

Alkali metal · Alkaline earth metal · Transition metal · Post-transition metal · Metalloid · Reactive non-metal · Halogen · Noble gas · Lanthanoid · Actinoid

PART 4

Properties of the elements

m.p. and b.p. at 101.325 kPa. IE_1 = first ionization energy; EA_1 = first electron affinity, with the second electron affinity of O and S shown in brackets. χ = Pauling electronegativity. [S] Arsenic sublimes at 613 °C.

Z	Element	A_r	m.p. / °C	b.p. / °C	IE_1 / kJ mol^{-1}	EA_1 / kJ mol^{-1}	χ (Pauling)	Atomic radius / pm	Ionic radius
1	**H** Hydrogen	1.01	−259.2	−252.9	1312	−73	2.2	32	
2	**He** Helium	4.00		−268.9	2372			37	
3	**Li** Lithium	6.94	180.5	1342	520	−60	1.0	130	76 (1+)
4	**Be** Beryllium	9.01	1287	2468	900		1.6	99	45 (2+)
5	**B** Boron	10.81	2077	4000	801	−27	2.0	84	27 (3+)
6	**C** Carbon	12.01	3500	4827	1086	−122	2.6	75	16 (4+)
7	**N** Nitrogen	14.01	−210.0	−195.8	1402		3.0	71	146 (3−)
8	**O** Oxygen	16.00	−218.8	−183.0	1314	−141 (+753)	3.4	64	140 (2−)
9	**F** Fluorine	19.00	−219.7	−188.1	1681	−328	4.0	60	133 (1−)
10	**Ne** Neon	20.18	−248.6	−246.0	2081			62	
11	**Na** Sodium	22.99	97.79	882.9	496	−53	0.9	160	102 (1+)
12	**Mg** Magnesium	24.31	650.0	1090	738		1.3	140	72 (2+)
13	**Al** Aluminium	26.98	660.3	2519	578	−42	1.6	124	54 (3+)
14	**Si** Silicon	28.09	1414	3265	787	−134	1.9	114	40 (4+)
15	**P** Phosphorus	30.97	44.15	280.5	1012	−72	2.2	109	38 (5+)
16	**S** Sulfur	32.07	115.2	444.6	1000	−200 (+545)	2.6	104	184 (2−)
17	**Cl** Chlorine	35.45	−101.5	−34.04	1251	−349	3.2	100	181 (1−)
18	**Ar** Argon	39.95	−189.3	−185.8	1520			101	
19	**K** Potassium	39.10	63.38	758.8	419	−48	0.8	200	138 (1+)
20	**Ca** Calcium	40.08	842.0	1484	590	−2	1.0	174	100 (2+)
21	**Sc** Scandium	44.96	1541	2836	633	−18	1.4	159	75 (3+)
22	**Ti** Titanium	47.87	1670	3287	659	−8	1.5	148	86 (2+), 61
23	**V** Vanadium	50.94	1910	3407	651	−51	1.6	144	79 (2+), 54
24	**Cr** Chromium	52.00	1907	2671	653	−64	1.7	130	62 (3+), 44
25	**Mn** Manganese	54.94	1246	2061	717		1.6	129	83 (2+), 53
26	**Fe** Iron	55.85	1538	2861	762	−15	1.8	124	61 (2+), 55
27	**Co** Cobalt	58.93	1495	2927	760	−64	1.9	118	65 (2+), 55
28	**Ni** Nickel	58.69	1455	2913	737	−112	1.9	117	69 (2+)
29	**Cu** Copper	63.55	1085	2560	745	−119	1.9	122	77 (1+), 73
30	**Zn** Zinc	65.38	419.5	907.0	906		1.6	120	74 (2+)
31	**Ga** Gallium	69.72	29.77	2229	579	−41	1.8	123	62 (3+)
32	**Ge** Germanium	72.63	938.2	2833	762	−119	2.0	120	53 (4+), 27
33	**As** Arsenic	74.92	816.8	613.0^{s}	944	−78	2.2	120	58 (3+), 46
34	**Se** Selenium	78.96	220.8	684.8	941	−195	2.6	118	198 (2−)
35	**Br** Bromine	79.90	−7.05	58.78	1140	−325	3.0	117	196 (1−)
36	**Kr** Krypton	83.80	−157.4	−153.4	1351			116	
37	**Rb** Rubidium	85.47	39.30	687.8	403	−47	0.8	215	152 (1+)
38	**Sr** Strontium	87.62	768.8	1377	549	−5	1.0	190	118 (2+)
39	**Y** Yttrium	88.91	1522	3345	600	−30	1.2	176	90 (3+)

Z	Element	A_r	m.p. / °C	b.p. / °C	IE_1 / kJ mol^{-1}	EA_1 / kJ mol^{-1}	χ (Pauling)	Atomic radius / pm	Ionic radius
40	**Zr** Zirconium	91.22	1854	4406	640	−41	1.3	164	72 (4+)
41	**Nb** Niobium	92.91	2477	4741	652	−88	1.6	156	72 (3+), 64
42	**Mo** Molybdenum	95.96	2622	4639	684	−72	2.2	146	65 (4+)
43	**Tc** Technetium	(98)	2157	4262	702	−53	2.1	138	65 (4+)
44	**Ru** Ruthenium	101.07	2333	4147	710	−101	2.2	136	68 (3+), 62
45	**Rh** Rhodium	102.91	1963	3695	720	−110	2.3	134	67 (3+), 60
46	**Pd** Palladium	106.42	1555	2963	804	−54	2.2	130	86 (2+), 62
47	**Ag** Silver	107.87	961.8	2162	731	−126	1.9	136	115 (1+)
48	**Cd** Cadmium	112.41	321.1	766.8	868		1.7	140	95 (2+)
49	**In** Indium	114.82	156.6	2027	558	−29	1.8	142	80 (3+)
50	**Sn** Tin	118.71	231.9	2586	709	−107	2.0	140	118 (2+), 6
51	**Sb** Antimony	121.76	630.6	1587	831	−101	2.0	140	76 (3+)
52	**Te** Tellurium	127.60	449.5	987.8	869	−190	2.1	137	221 (2−)
53	**I** Iodine	126.90	113.7	184.4	1008	−295	2.7	136	220 (1−)
54	**Xe** Xenon	131.29	−111.8	−108.1	1170		2.6	136	
55	**Cs** Caesium	132.91	28.44	670.8	376	−46	0.8	238	167 (1+)
56	**Ba** Barium	137.33	725.0	1845	503	−14	0.9	206	135 (2+)
57	**La** Lanthanum	138.91	920.0	3464	538	−45	1.1	194	103 (3+)
72	**Hf** Hafnium	178.49	2233	4600	659	−1	1.3	164	71 (4+)
73	**Ta** Tantalum	180.95	3017	5455	728	−31	1.5	158	64 (5+)
74	**W** Tungsten	183.84	3414	5555	759	−79	1.7	150	66 (4+), 60
75	**Re** Rhenium	186.21	3453	5900	756	−14	1.9	141	63 (4+), 53
76	**Os** Osmium	190.23	3033	5008	814	−106	2.2	136	63 (4+), 55
77	**Ir** Iridium	192.22	2446	4428	865	−151	2.2	132	68 (3+), 63
78	**Pt** Platinum	195.08	1768	3825	864	−205	2.2	130	80 (2+), 63
79	**Au** Gold	196.97	1064	2836	890	−223	2.4	130	137 (1+), 8
80	**Hg** Mercury	200.59	−38.83	356.6	1007		1.9	132	119 (1+), 1
81	**Tl** Thallium	204.38	303.8	1473	589	−36	1.8	144	150 (1+), 8
82	**Pb** Lead	207.20	327.5	1749	716	−35	1.8	145	119 (2+), 7
83	**Bi** Bismuth	208.98	271.4	1564	703	−91	1.9	150	103 (3+), 7
84	**Po** Polonium	(209)	253.8	962.0	812	−183	2.0	142	97 (4+)
85	**At** Astatine	(210)	301.8	336.8		−270	2.2	148	
86	**Rn** Radon	(222)	−71.15	−61.85	1037			146	
87	**Fr** Francium	(223)	27.00	676.8	393	−47	0.7	242	
88	**Ra** Radium	(226)	699.8	1140	509	−10	0.9	211	
89	**Ac** Actinium	(227)	1050	3200	499	−34	1.1	201	

Lanthanoids and actinoids

Z	Element	A_r	m.p. / °C	b.p. / °C	IE_1 / kJ mol^{-1}	χ (Pauling)	Ionic radius / pm (ch
58	**Ce** Cerium	140.12	795	3433	534	1.1	101 (3+), 87 (4+)
59	**Pr** Praseodymium	140.91	935	3510	528	1.1	99 (3+), 85 (4+)
60	**Nd** Neodymium	144.24	1024	3074	533	1.1	98 (3+)
61	**Pm** Promethium	(145)	1042	(2730)	539		97 (3+)
62	**Sm** Samarium	150.36	1072	1791	545	1.2	96 (3+)
63	**Eu** Europium	151.96	826	1596	547		117 (2+), 95 (3+)
64	**Gd** Gadolinium	157.25	1313	3273	593	1.2	94 (3+)
65	**Tb** Terbium	158.93	1360	3230	566		92 (3+), 76 (4+)
66	**Dy** Dysprosium	162.50	1410	2567	573	1.2	91 (3+)
67	**Ho** Holmium	164.93	1472	2694	581	1.2	90 (3+)
68	**Er** Erbium	167.26	1529	2900	589	1.2	89 (3+)
69	**Tm** Thulium	168.93	1545	1950	597	1.3	88 (3+)
70	**Yb** Ytterbium	173.05	824	1194	603		87 (3+)
71	**Lu** Lutetium	174.97	1663	3042	524	1.3	86 (3+)
90	**Th** Thorium	232.04	1750	4788	609	1.3	94 (4+)
91	**Pa** Protactinium	231.04	1572	(4000)	568	1.5	104 (3+), 90 (4+)
92	**U** Uranium	238.03	1135	3818	598	1.7	89 (4+), 73 (6+)
93	**Np** Neptunium	(237)	637	(3900)	605	1.3	101 (3+), 87 (4+)
94	**Pu** Plutonium	(244)	640	3230	581	1.3	100 (3+), 86 (4+)
95	**Am** Americium	(243)	1176	(2067)	576		98 (3+), 85 (4+)
96	**Cm** Curium	(247)	1340	3110	578		97 (3+)
97	**Bk** Berkelium	(247)	986	(2623)	598		96 (3+)
98	**Cf** Californium	(251)	900		606		99 (3+)
99	**Es** Einsteinium	(252)	(860)		619		
100	**Fm** Fermium	(257)			627		
101	**Md** Mendelevium	(258)	827		635		
102	**No** Nobelium	(259)			642		110 (2+)
103	**Lr** Lawrencium	(262)			473		

Values in brackets for melting and boiling points are estimates.

PART 5

Covalent bonds: lengths and enthalpies

Bond enthalpies are average values at 298.15 K, except for diatomic molecules where they are exact. Lengths in picometres (1 pm = 10^{-12} m).

Single bonds

Bond	Length / pm	Enthalpy / kJ mol^{-1}
Br–Br	228	193
Br–C	194	285
Br–Cl	214	219
Br–F	176	249
Br–H	141	366
Br–I	247	178
Br–N	214	—
Br–O	—	201
Br–P	220	264
Br–S	227	218
Br–Si	216	330
C–C	154	346
C–Cl	177	324
C–F	138	492
C–H	108	414
C–I	214	228
C–N	147	286
C–O	143	358
C–P	184	264
C–S	182	289
C–Si	185	307

Bond	Length / pm	Enthalpy / kJ mol^{-1}
Cl–Cl	199	242
Cl–F	163	255
Cl–H	128	431
Cl–I	232	211
Cl–N	175	192
Cl–O	170	206
Cl–P	203	322
Cl–S	199	271
Cl–Si	202	400
F–F	142	159
F–H	92	567
F–I	191	280
F–N	136	278
F–O	142	191
F–P	154	490
F–S	158	327
F–Si	156	597
H–H	74	436
H–I	160	298
H–N	101	391
H–O	97	463

Bond	Length / pm	Enthalpy / kJ mol^{-1}
H–P	142	322
H–S	134	364
H–Si	148	323
I–I	267	151
I–O	—	201
I–P	247	184
I–Si	243	234
N–N	146	158
N–O	136	214
N–S	175	—
N–Si	174	—
O–O	148	144
O–P	154	363
O–S	161	—
O–Si	163	466
P–P	221	198
P–S	210	—
S–S	205	266
S–Si	215	293
Si–Si	232	226

Multiple bonds

Bond	Length / pm	Enthalpy / kJ mol^{-1}
C=C	134	614
C≡C	120	839
C=N	130	615
C≡N	116	890
C=O	122	804

Bond	Length / pm	Enthalpy / kJ mol^{-1}
C≡O	113	1077
C=S	156	536
N=N	125	470
N≡N	110	945

Bond	Length / pm	Enthalpy / kJ mol^{-1}
N=O	114	587
O=O	121	498
O=S	143	522
S=S	189	429

PART 6

Thermochemical data

Standard values at 298.15 K: enthalpy of formation $\Delta H_f^\ominus$ and Gibbs energy of formation $\Delta G_f^\ominus$ (kJ mol⁻¹), standard entropy $S^\ominus$ (J K⁻¹ mol⁻¹), and enthalpy of combustion $\Delta H_c^\ominus$ (kJ mol⁻¹, measured at SATP).

Substance	Formula	State	$\Delta H_f^\ominus$	$\Delta G_f^\ominus$	$S^\ominus$	$\Delta H_c^\ominus$
ALKANES AND CYCLOALKANES						
Methane	CH_4	g	−74	−50	186	−891
Ethane	C_2H_6	g	−84	−32	230	−1561
Propane	C_3H_8	g	−105	−24	270	−2219
Butane	C_4H_{10}	g	−126	−17	310	−2878
Pentane	C_5H_{12}	l	−173			−3509
Hexane	C_6H_{14}	l	−199			−4163
Octane	C_8H_{18}	l				−5470
Cyclohexane	C_6H_{12}	l	−156			−3920
ALKENES, DIENES AND ALKYNES						
Ethene	C_2H_4	g	+52	+68	220	−1411
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	
Buta-1,3-diene	C_4H_6	g	+110	+151	279	−2541
Ethyne	C_2H_2	g	+228	+211	201	−1301
Propyne	C_3H_4	g	+185	+194	248	
ARENES						
Benzene	C_6H_6	l	+49	+125	173	−3268
Methylbenzene	$C_6H_5CH_3$	l	+12			−3910
Ethylbenzene	$C_6H_5CH_2CH_3$	l	−12			
Phenylethene	$C_6H_5CHCH_2$	l	+104			
Naphthalene	$C_{10}H_8$	s				−5156
HALOGENOALKANES AND HALOGENOARENES						
Chloromethane	CH_3Cl	g	−82	−58	235	
Dichloromethane	CH_2Cl_2	l	−124		178	
Trichloromethane	$CHCl_3$	l	−134	−74	202	−473
Bromomethane	CH_3Br	g	−36	−26	246	
Iodomethane	CH_3I	l	−14		163	
Chloroethane	C_2H_5Cl	g	−112	−60		−1413
Bromoethane	C_2H_5Br	l	−90	−26	199	
Iodoethane	C_2H_5I	l				−1463
Chlorobenzene	C_6H_5Cl	l	+11			

Substance	Formula	State	$\Delta H_f^\ominus$	$\Delta G_f^\ominus$	$S^\ominus$	$\Delta H_c^\ominus$
ALCOHOLS, PHENOLS AND ETHERS						
Methanol	CH_3OH	l	−239	−167	127	−726
Ethanol	C_2H_5OH	l	−278	−175	161	−1367
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	−165		144	−3053
Ethoxyethane	$(C_2H_5)_2O$	l				−2724
ALDEHYDES AND KETONES						
Methanal	$HCHO$	g	−109	−102	219	−571
Ethanal	CH_3CHO	g	−166	−133	264	−1167
Benzaldehyde	C_6H_5CHO	l				−3525
Propanone	$(CH_3)_2CO$	l	−248		200	−1790
Pentan-3-one	$(C_2H_5)_2CO$	l				−3100
Phenylethanone	$CH_3COC_6H_5$	l				−4149
CARBOXYLIC ACIDS, ESTERS AND NITROGEN COMPOUNDS						
Methanoic acid	$HCOOH$	l	−425	−361	129	−255
Ethanoic acid	CH_3COOH	l	−484	−390	160	−874
Benzoic acid	C_6H_5COOH	s	−385		168	−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	−23	+32	243	−1086
Phenylamine	$C_6H_5NH_2$	l				−3393
Nitrobenzene	$C_6H_5NO_2$	l				−3088
Urea	$CO(NH_2)_2$	s				−633
CARBOHYDRATES						
Glucose	$C_6H_{12}O_6$	s				−2803
Sucrose	$C_{12}H_{22}O_{11}$	s				−5640
ELEMENTS AND INORGANIC COMPOUNDS						
Hydrogen	H_2	g				−286
Carbon (graphite)	C	s				−394
Sulfur	S	s				−297
Carbon monoxide	CO	g	−111	−137	198	−283
Carbon dioxide	CO_2	g	−394	−394	214	

Substance	Formula	State	$\Delta H_f^\ominus$	$\Delta G_f^\ominus$	$S^\ominus$	$\Delta H_c^\ominus$
Water	H_2O	l	−286	−237	70	
Steam	H_2O	g	−242	−229	189	
Hydrogen fluoride	HF	g	−273	−275	174	
Hydrogen chloride	HCl	g	−92	−95	187	
Hydrogen bromide	HBr	g	−36	−53	199	
Hydrogen iodide	HI	g	+26	+2	207	

PART 7

Lattice enthalpies and bonding

Lattice enthalpy $\Delta H^{\ominus}_{\text{lattice}}$ (kJ mol^{-1}, 298.15 K) is the endothermic change $\mathrm{M_aX_b(s)} \rightarrow \mathrm{aM^{b+}(g) + bX^{a-}(g)}$. Experimental values from Born–Haber cycles.

Group 1 halides

	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

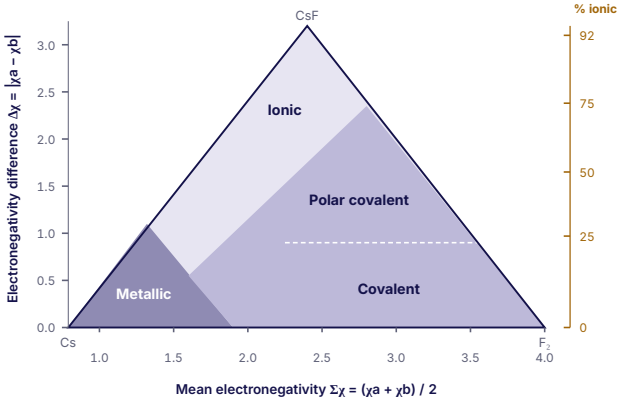
Group 2 compounds

Compound	Value
$BeCl_2$	3033
$MgCl_2$	2540
$CaCl_2$	2271
$SrCl_2$	2170
$BaCl_2$	2069
CaF_2	2651
MgO	3791
CaO	3401
SrO	3223
BaO	3054

Transition metal compounds

Compound	Value
$CuCl_2$	2824
AgF	974
AgCl	918
AgBr	905
AgI	892

Bonding triangle (van Arkel–Ketelaar)



Locate a binary substance from the mean and the difference of the two electronegativities to predict its dominant bonding type.

Colour wheel



A substance that absorbs light of one colour appears the complementary colour, on the opposite side of the wheel. Boundaries are wavelengths in nm.

PART 8

Acids, bases and redox

Acid–base indicators

Indicator	pK_a	pH range of colour change	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	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

Standard electrode (reduction) potentials at 298.15 K

Half-equation (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**

Species higher in the table are stronger reducing agents (as the reduced form); species lower down are stronger oxidizing agents.

PART 9

Spectroscopic data

Infrared absorptions (stretching vibrations)

Bond	Found in	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 to weak; several bands
C=O	aldehydes, ketones, carboxylic acids, esters	1700 – 1750	strong
C≡C	alkynes	2100 – 2260	variable
O–H	carboxylic acids (hydrogen bonded)	2500 – 3000	strong, very broad
C–H	alkanes, alkenes, arenes	2850 – 3090	strong
O–H	alcohols and phenols (hydrogen bonded)	3200 – 3600	strong, broad
N–H	primary amines	3300 – 3500	medium, two bands

^{1}H NMR chemical shifts (relative to TMS, δ = 0)

Proton environment	Structure (proton in bold)	δ / ppm
Alkyl, terminal methyl	R–C**H$_3$**	**0.9 – 1.0**
Alkyl, methylene	R–C**H$_2$**–R	**1.3 – 1.4**
Alkyl, methine	R$_3$C**H**	**1.5**
Alcohol hydroxyl	R–O–**H**	**1.0 – 6.0**
Terminal alkyne	–C≡C–**H**	**1.8 – 3.1**
Next to an ester carbonyl (acid side)	RO–CO–C**H$_2$**–	**2.0 – 2.5**
Next to a ketone/aldehyde carbonyl	R–CO–C**H$_2$**–	**2.2 – 2.7**
Methyl on a benzene ring	C$_6$H$_5$–C**H$_3$**	**2.5 – 3.5**
Ether, next to O	R–O–C**H$_2$**–	**3.3 – 3.7**
Next to a halogen	–C**H$_2$**–Hal	**3.5 – 4.4**
Ester, next to O (alcohol side)	R–CO–O–C**H$_2$**–	**3.7 – 4.8**
Phenol hydroxyl	C$_6$H$_5$–O**H**	**4.0 – 12.0**
Alkene	–CH=C**H$_2$**	**4.5 – 6.0**
Aromatic ring	C$_6$**H$_5$**–	**6.9 – 9.0**
Carboxylic acid	R–COO**H**	**9.0 – 13.0**
Aldehyde	R–C**H**O	**9.4 – 10.0**

R = alkyl group; Hal = F, Cl, Br or I. Shifts vary with solvent and conditions.

Mass spectrometry: common neutral fragments lost

Mass lost	Possible fragment
15	•CH$_3$
17	•OH
18	H$_2$O
28	CH$_2$=CH$_2$ or C=O
29	•CH$_2$CH$_3$ or •CHO
31	•OCH$_3$
45	•COOH

Data compiled by IB Demystified from standard reference sources, including the CRC Handbook of Chemistry and Physics, Aylward and Findlay's SI Chemical Data, the NIST Chemistry WebBook and IUPAC recommendations. Bonding triangle redrawn after the van Arkel–Ketelaar diagram as presented by M. R. Leach (Chemogenesis Web Book).

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