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1. Some relevant equations

Speed, frequency and wavelength of light	$c = f\lambda$ PHOTON NOTE Wavelength must be in metres when you use $c = 3.00 \times 10^8 \text{ m s}^{-1}$, so convert nm first.
Energy of a photon	$E = hf$ PHOTON NOTE This is the energy of ONE photon; multiply by the Avogadro constant for a value per mole.
Amount from mass	$n = \frac{m}{M}$ PHOTON NOTE With m in grams, M is in g mol^{-1} (the relative mass from the periodic table).
Amount from concentration	$n = CV$ PHOTON NOTE V must be in dm^3 : divide cm^3 by 1000 before you multiply.
Ideal gas equation	$PV = nRT$ PHOTON NOTE With $R = 8.31$ use SI units only: P in Pa, V in m^3 , T in K.
Combined gas law	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$ PHOTON NOTE For a fixed amount of gas; any units for P and V work if they match on both sides, but T must be in kelvin.
Heat change	$Q = mc\Delta T$ PHOTON NOTE m is the mass of the substance being heated (usually the water), not the mass of the fuel or solid reactant.

Atom economy	$\% \text{ atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100$ PHOTON NOTE Use the balanced equation, so include stoichiometric coefficients when adding up the reactant masses.
Enthalpy change from enthalpies of formation	$\Delta H^{\ominus} = \sum (\Delta H_f^{\ominus} \text{ products}) - \sum (\Delta H_f^{\ominus} \text{ reactants})$ PHOTON NOTE Products minus reactants; elements in their standard states have a value of zero.
Enthalpy change from enthalpies of combustion	$\Delta H^{\ominus} = \sum (\Delta H_c^{\ominus} \text{ reactants}) - \sum (\Delta H_c^{\ominus} \text{ products})$ PHOTON NOTE The order flips here: reactants minus products. Mixing this up with the formation version is a classic error.
Gibbs energy change	$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ PHOTON NOTE ΔS is usually in $\text{J K}^{-1} \text{ mol}^{-1}$ and ΔH in kJ mol^{-1}: divide ΔS by 1000 before combining.
Gibbs energy and reaction quotient	$\Delta G = \Delta G^{\ominus} + RT \ln Q$ PHOTON NOTE Shows how ΔG changes as a reaction mixture moves towards equilibrium, where $\Delta G = 0$ and $Q = K$.
Gibbs energy and equilibrium constant	$\Delta G^{\ominus} = -RT \ln K$ PHOTON NOTE A negative $\Delta G^{\ominus}$ gives $K > 1$. Use $\Delta G^{\ominus}$ in J mol^{-1} because R is in $\text{J K}^{-1} \text{ mol}^{-1}$.
Gibbs energy and cell potential	$\Delta G^{\ominus} = -nFE^{\ominus}$ PHOTON NOTE n is the number of moles of electrons transferred; the answer comes out in J mol^{-1}.
Arrhenius equation	$k = Ae^{\frac{-E_a}{RT}}$ PHOTON NOTE E_a in J mol^{-1} here, to match R; a higher temperature or lower E_a gives a larger k.
Arrhenius equation (logarithmic form)	$\ln k = \frac{-E_a}{RT} + \ln A$ PHOTON NOTE Plot $\ln k$ against $1/T$: the gradient is $-E_a/R$ and the y-intercept is $\ln A$.
pH	$\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] \quad \text{or} \quad \text{pH} = -\log_{10}[\text{H}^+]$ PHOTON NOTE The two forms mean the same thing; a change of 1 pH unit is a tenfold change in $[\text{H}^+]$.
Ionic product of water	$K_w = [\text{H}^+][\text{OH}^-]$ PHOTON NOTE $K_w = 1.00 \times 10^{-14}$ only at 298.15 K; it rises with temperature, so neutral pH is below 7 when hot.
pOH	$\text{pOH} = -\log_{10}[\text{OH}^-]$ PHOTON NOTE Find pOH for a base first, then convert to pH using $\text{pH} + \text{pOH} = 14$ at 298 K.

Percentage yield

$$\% \text{ yield} = \frac{\text{experimental yield}}{\text{theoretical yield}} \times 100$$

Work out the theoretical yield from the limiting reactant.

Molar volume at STP

$$n = \frac{V}{V_m} = \frac{V}{22.7 \text{ dm}^3 \text{ mol}^{-1}}$$

Only for gases at STP; use $PV = nRT$ at any other conditions.

Enthalpy change from a calorimetry experiment

$$\Delta H = -\frac{Q}{n}$$

The minus sign: the surroundings warm up in an exothermic reaction, so ΔH is negative. Convert Q to kJ.

Enthalpy change from bond enthalpies

$$\Delta H = \sum(\text{bonds broken}) - \sum(\text{bonds formed})$$

Reactants minus products here, and only for gases.

Hess's law

$$\Delta H_1 = \Delta H_2 + \Delta H_3$$

The total enthalpy change is the same whichever route links the same start and end; reverse a step and flip its sign.

Entropy change of a reaction (HL)

$$\Delta S^\ominus = \sum S^\ominus_{\text{products}} - \sum S^\ominus_{\text{reactants}}$$

Elements have non-zero standard entropies, unlike enthalpies of formation.

Equilibrium constant

$$K = \frac{[C]^c[D]^d}{[A]^a[B]^b} \text{ for } aA + bB \rightleftharpoons cC + dD$$

Leave out pure solids and liquids; the reaction quotient Q has the same form with non-equilibrium concentrations.

Rate of reaction

$$\text{rate} = \frac{\Delta[\text{product}]}{\Delta t} = -\frac{\Delta[\text{reactant}]}{\Delta t}$$

The gradient of a concentration–time graph; draw a tangent for an instantaneous rate.

Rate equation (HL)

$$\text{rate} = k[A]^m[B]^n$$

Orders come from experiment, not from the balanced equation.

Half-life of a first-order reaction (HL)

$$t_{\frac{1}{2}} = \frac{\ln 2}{k}$$

A constant half-life is the sign of a first-order reaction.

Arrhenius equation at two temperatures (HL)

$$\ln \frac{k_2}{k_1} = \frac{E_a}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right)$$

Follows from subtracting the booklet's $\ln$ form at two temperatures; A cancels.

pH + pOH

$$\text{pH} + \text{pOH} = 14.00 \text{ at } 298 \text{ K}$$

Comes from $K_w = 1.00 \times 10^{-14}$; at other temperatures use $\text{p}K_w$.

Acid dissociation constant (HL)

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} \quad \text{p}K_a = -\log_{10} K_a$$

For a weak acid assume $[\text{H}^+] = [\text{A}^-]$ and that $[\text{HA}]$ stays at its starting value.

Conjugate pairs (HL)

$$K_a \times K_b = K_w \quad \text{p}K_a + \text{p}K_b = \text{p}K_w$$

Applies to an acid and its own conjugate base only.

Standard cell potential (HL)

$$E_{\text{cell}}^{\ominus} = E_{\text{cathode}}^{\ominus} - E_{\text{anode}}^{\ominus}$$

Use reduction potentials from section 19 as printed; a positive $E_{\text{cell}}^{\ominus}$ means a spontaneous reaction.

Empirical and molecular formula

$$\text{molecular formula} = \left(\frac{M_r}{\text{empirical formula mass}} \right) \times \text{empirical formula}$$

Get the empirical formula from the mole ratio, dividing each amount by the smallest.

Molar mass from gas data

$$M = \frac{mRT}{PV}$$

Combines $PV = nRT$ with $n = m/M$; keep SI units throughout.

2. Physical constants

Quantity	Symbol	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	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
PHOTON NOTE The joules mean energies must be in J (not kJ) whenever R appears.		
Molar volume of an ideal gas at STP	V_m	$2.27 \times 10^{-2} \text{ m}^3 \text{ mol}^{-1} = 22.7 \text{ dm}^3 \text{ mol}^{-1}$
PHOTON NOTE Only at STP (273.15 K, 100 kPa); at other conditions use $PV = nRT$.		
Specific heat capacity of water	c_w	$4.18 \text{ kJ kg}^{-1} \text{ K}^{-1} = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$
PHOTON NOTE With mass in grams this gives Q in joules.		
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	$9.65 \times 10^4 \text{ C mol}^{-1}$
PHOTON NOTE The charge on one mole of electrons, $F = N_A \times e$.		

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 ($^{\circ}\text{C}$) + 273.15

PHOTON NOTE

Any equation with T in it (gas laws, ΔG , Arrhenius) needs kelvin.

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

PHOTON NOTE

For $PV = nRT$, $1 \text{ dm}^3 = 10^{-3} \text{ m}^3$ is the step most often missed.

STP conditions: 273.15 K and 100 kPa

PHOTON NOTE

The molar volume $22.7 \text{ dm}^3 \text{ mol}^{-1}$ applies here.

SATP conditions: 298.15 K and 100 kPa

PHOTON NOTE

Standard ($\ominus$) thermodynamic data in the booklet refer to 298.15 K.

NOT IN THE IB BOOKLET · LEARN OR DERIVE THESE

Density of water

$$\rho_{\text{water}} \approx 1.00 \text{ g cm}^{-3}$$

So 1 cm^3 of dilute solution is taken as 1 g in calorimetry.

pH of pure water at 298 K

$$\text{pH} = 7.00$$

Neutral means $[\text{H}^+] = [\text{OH}^-]$, which is pH 7 only at 298 K.

PHOTON NOTE

A wavelength scale from about 10^{-16} m to 10^8 m running from gamma rays through X-rays, UV, visible, IR and microwaves to radio waves, with energy increasing towards short wavelengths; the visible band is roughly 400 nm (violet) to 700 nm (red).

7. The periodic table

Atomic number, symbol and relative atomic mass. Hover or tap an element for its name.

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)

12. Bond enthalpies or average bond enthalpies at 298.15 K: Single bonds

Bond	Enthalpy / kJ mol^{-1}
H—H	436
H—F	567
H—Cl	431
H—Br	366
H—I	298
C—H	414
C—C	346
C—N	286
C—O	358
C—Si	307
C—P	264
C—S	289
C—F	492
C—Cl	324
C—Br	285
C—I	228
N—H	391
N—N	158
N—O	214
N—F	278
N—Cl	192
O—H	463
O—O	144
O—Si	466
O—P	363
O—F	191
O—Cl	206
O—Br	201
O—I	201
Si—H	323
Si—Si	226
Si—S	293
Si—F	597
Si—Cl	400
Si—Br	330

Bond	Enthalpy / kJ mol ⁻¹
Si—I	234
P—H	322
P—P	198
P—F	490
P—Cl	322
P—Br	264
P—I	184
S—H	364
S—S	266
S—F	327
S—Cl	271
S—Br	218
F—F	159
F—Cl	255
F—Br	249
F—I	280
Cl—Cl	242
Cl—Br	219
Cl—I	211
Br—Br	193
Br—I	178
I—I	151

PHOTON NOTE

Average values are for bonds in the gas phase, so bond-enthalpy answers differ a little from values worked out with enthalpies of formation. The booklet lays these out in four column pairs; we list them one pair after another.

12. Bond enthalpies or average bond enthalpies at 298.15 K: Multiple bonds

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

PHOTON NOTE

Bond enthalpy rises from single to double to triple bonds between the same atoms, and bond length falls; use the right bond order when you count bonds broken and formed.

14. Enthalpies of combustion

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 ₂ H ₆	g	-1561
propane	C ₃ H ₈	g	-2219
butane	C ₄ H ₁₀	g	-2878
pentane	C ₅ H ₁₂	l	-3509
hexane	C ₆ H ₁₄	l	-4163
octane	C ₈ H ₁₈	l	-5470
cyclohexane	C ₆ H ₁₂	l	-3920
ethene	C ₂ H ₄	g	-1411
buta-1,3-diene	C ₄ H ₆	g	-2541
ethyne	C ₂ H ₂	g	-1301
benzene	C ₆ H ₆	l	-3268
methylbenzene	C ₆ H ₅ CH ₃	l	-3910
naphthalene	C ₁₀ H ₈	s	-5156
chloroethane	C ₂ H ₅ Cl	g	-1413
iodoethane	C ₂ H ₅ I	l	-1463
trichloromethane	CHCl ₃	l	-473
methanol	CH ₃ OH	l	-726
ethanol	C ₂ H ₅ OH	l	-1367
propan-1-ol	C ₃ H ₇ OH	l	-2021
butan-1-ol	C ₄ H ₉ OH	l	-2676
cyclohexanol	C ₆ H ₁₁ OH	s	-3728
phenol	C ₆ H ₅ OH	s	-3053
ethoxyethane	(C ₂ H ₅) ₂ O	l	-2724
methanal	HCHO	g	-571
ethanal	CH ₃ CHO	g	-1167
benzaldehyde	C ₆ H ₅ CHO	l	-3525
propanone	(CH ₃) ₂ CO	l	-1790
pentan-3-one	(C ₂ H ₅) ₂ CO	l	-3100
phenylethanone	CH ₃ COC ₆ H ₅	l	-4149
methanoic acid	HCOOH	l	-255

Substance	Formula	State	$\Delta H_c^\ominus$ / kJ mol ⁻¹
ethanoic acid	CH ₃ COOH	l	-874
benzoic acid	C ₆ H ₅ COOH	s	-3228
ethanedioic acid	(COOH) ₂	s	-243
ethyl ethanoate	CH ₃ COOC ₂ H ₅	l	-2238
ethanamide	CH ₃ CONH ₂	s	-1186
methylamine	CH ₃ NH ₂	g	-1086
phenylamine	C ₆ H ₅ NH ₂	l	-3393
nitrobenzene	C ₆ H ₅ NO ₂	l	-3088
urea	CO(NH ₂) ₂	s	-633
glucose	C ₆ H ₁₂ O ₆	s	-2803
sucrose	C ₁₂ H ₂₂ O ₁₁	s	-5640

PHOTON NOTE

Values are per mole of the substance burned, at 298.15 K and 100 kPa, with water formed as a liquid. Down a homologous series each extra CH₂ adds roughly 650 kJ mol⁻¹.

18. Acid–base indicators

Indicator	pK_a	pH range	Colour change: Acid	Colour change: 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

PHOTON NOTE

Pick an indicator whose colour-change range sits inside the steep part of the titration curve, i.e. its pK_a is close to the pH at the equivalence point.

19. Standard reduction potentials at 298.15 K

Oxidized species		Reduced species	$E^\ominus / \text{V}$
$\text{Li}^+(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Li}(\text{s})$	-3.04
$\text{K}^+(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{K}(\text{s})$	-2.93
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Ca}(\text{s})$	-2.87
$\text{Na}^+(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Na}(\text{s})$	-2.71
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Mg}(\text{s})$	-2.37
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^-$	$\rightleftharpoons$	$\text{Al}(\text{s})$	-1.66
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Mn}(\text{s})$	-1.18
$\text{H}_2\text{O}(\text{l}) + \text{e}^-$	$\rightleftharpoons$	$\frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^-(\text{aq})$	-0.83
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Zn}(\text{s})$	-0.76
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Fe}(\text{s})$	-0.45
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Ni}(\text{s})$	-0.26
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Sn}(\text{s})$	-0.14
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Pb}(\text{s})$	-0.13
$\text{H}^+(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\frac{1}{2}\text{H}_2(\text{g})$	0.00
$\text{Cu}^{2+}(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Cu}^+(\text{aq})$	+0.15
$\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.17
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{Cu}(\text{s})$	+0.34
$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^-$	$\rightleftharpoons$	$2\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^+(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Cu}(\text{s})$	+0.52
$\frac{1}{2}\text{I}_2(\text{s}) + \text{e}^-$	$\rightleftharpoons$	$\text{I}^-(\text{aq})$	+0.54
$\text{Fe}^{3+}(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	+0.77
$\text{Ag}^+(\text{aq}) + \text{e}^-$	$\rightleftharpoons$	$\text{Ag}(\text{s})$	+0.80
$\frac{1}{2}\text{Br}_2(\text{l}) + \text{e}^-$	$\rightleftharpoons$	$\text{Br}^-(\text{aq})$	+1.09
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$	$\rightleftharpoons$	$\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^-$	$\rightleftharpoons$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.36
$\frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^-$	$\rightleftharpoons$	$\text{Cl}^-(\text{aq})$	+1.36
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^-$	$\rightleftharpoons$	$\text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
$\frac{1}{2}\text{F}_2(\text{g}) + \text{e}^-$	$\rightleftharpoons$	$\text{F}^-(\text{aq})$	+2.87

PHOTON NOTE

The more positive $E^\ominus$, the stronger the oxidizing agent on the left; the more negative, the stronger the reducing agent on the right. Do not multiply $E^\ominus$ when you scale a half-equation.

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

PHOTON NOTE

A carboxylic acid shows both the very broad O—H band and the sharp C=O band; check for both before naming the functional group.

21. ^1H NMR data: Typical proton chemical shift values (δ) relative to tetramethylsilane (TMS)

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
$-\text{C}_6\text{H}_4-\text{CH}_3$ (CH_3 on a benzene ring)	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
$-\text{C}_6\text{H}_4-\text{OH}$ (OH on a benzene ring)	4.0–12.0
$-\text{C}_6\text{H}_4-\text{H}$ (H on a benzene ring)	6.9–9.0
$\text{R}-\text{C}(=\text{O})-\text{H}$	9.4–10.0

PHOTON NOTE

R is an alkyl group and Hal is F, Cl, Br or I; values can shift with solvent and conditions. The booklet draws the $\text{C}=\text{O}$ groups and benzene rings as structures: we write them as condensed formulas ($\text{C}(=\text{O})$ is a carbonyl, C_6H_4 a benzene ring) and, as in the booklet, the proton being described is in bold.

22. Mass spectral fragments lost

Mass lost (M_r)	Possible neutral fragment lost
15	•CH ₃
17	•OH
18	H ₂ O
28	CH ₂ =CH ₂ , CO
29	•CH ₂ CH ₃ , •CHO
31	•OCH ₃
45	•COOH

PHOTON NOTE

Read these as gaps between the molecular ion peak and a fragment peak. Where the booklet lists two fragments side by side for one mass, we separate them with a comma.

23. Uncertainties

If: $y = a \pm b$

then:

$$\Delta y = \Delta a + \Delta b$$

PHOTON NOTE

Adding or subtracting: add the absolute uncertainties (e.g. two burette readings).

If: $y = \frac{ab}{c}$

then:

$$\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$

PHOTON NOTE

Multiplying or dividing: add the fractional (or percentage) uncertainties.

If: $y = a^n$

then:

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

PHOTON NOTE

A power multiplies the fractional uncertainty by n.

NOT IN THE IB BOOKLET · LEARN OR DERIVE THESE

NMR reference

$$\delta_{\text{TMS}} = 0 \text{ ppm}$$

TMS gives one strong signal upfield of almost all organic protons, so it is used as the zero.

Splitting pattern (HL)

n neighbouring H on adjacent C $\rightarrow n + 1$ peaks

Protons on the same carbon, and O—H protons, usually do not split each other.

In the official booklet, not retyped here

- **8. Melting points and boiling points of the elements at 101.325 kPa** A periodic-table layout giving each element's melting and boiling point in °C.
- **9. First ionization energy, electron affinity and electronegativity of the elements** A periodic-table layout with first ionization energies and electron affinities in kJ mol^{-1} (a few second EAs) and electronegativities.
- **10. Atomic and ionic radii of the elements** A periodic-table layout with covalent (atomic) radii and common ionic radii with their charges, in units of 10^{-12} m .
- **11. Covalent or average covalent bond lengths** Lengths of common single and multiple bonds, in units of 10^{-12} m .
- **13. Thermodynamic data (selected compounds)** Standard enthalpy of formation, Gibbs energy of formation and standard entropy for over 40 selected compounds, mostly organic.
- **15. Colour wheel with wavelengths of the visible spectrum** A colour wheel of red, orange, yellow, green, blue and violet with boundary wavelengths from 400 nm to 700 nm, for complementary colours.
- **16. Lattice enthalpies at 298.15 K (experimental values)** Experimental Born–Haber lattice enthalpies for the alkali metal halides and a set of other ionic compounds.
- **17. Triangular bonding diagram (van Arkel–Ketelaar triangle)** A triangle plotting electronegativity difference against average electronegativity, with regions for ionic, polar covalent, covalent and metallic bonding.
- **24. References** The data sources the IB used for the tables.

These are long data tables. Use the official booklet for them.

Source: Diploma Programme Chemistry data booklet, first assessment 2025, version 1.1 (published February 2023, updated February 2024), retyped by Photon Resources. This is an unofficial study companion, not produced or endorsed by the International Baccalaureate. In the exam you use the clean official booklet your school provides. All notes and extra facts are ours.