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Notes

This booklet cannot be used for paper 1 of the examination (SLP1 and HLP1), but the periodic table given in section 6 will be available as part of these examination papers. Clean copies of this booklet must be made available to candidates for papers 2 and 3 (SLP2, HLP2, SLP3 and HLP3).

1. Some relevant equations

Topic	Equation
1.3	$PV = nRT$
2.2 and C.4	$c = v\lambda$
5.1	$q = mc\Delta T$
8.3	$pH = -\log_{10}[\text{H}_3\text{O}^+]$ or $pH = -\log_{10}[\text{H}^+]$
12.1	$E = h\nu$
15.2	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$
16.2	$k = Ae^{\frac{-E_a}{RT}}$
16.2	$\ln k = \frac{-E_a}{RT} + \ln A$
16.2	$\ln \frac{k_1}{k_2} = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$
17.1	$\Delta G^\circ = -RT \ln K$
19.1	$\Delta G^\circ = -nFE^\circ$
A.5	$\% \text{ atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100$
A.8	$n\lambda = 2d\sin\theta$
B.7	$pH = pK_a + \log \left(\frac{[\text{A}^-]}{[\text{HA}]}\right)$
B.7	$\log_{10} \frac{I_0}{I} = \epsilon lc$

Topic	Equation
C.1	Energy density = $\frac{\text{energy released from fuel}}{\text{volume of fuel consumed}}$
C.1	Specific energy = $\frac{\text{energy released from fuel}}{\text{mass of fuel consumed}}$
C.3	$N = N_0 e^{-\lambda t}$
C.3 and D.8	$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
C.6	$E = E^0 - \left(\frac{RT}{nF}\right) \ln Q$
C.7	$\frac{\text{Rate}_1}{\text{Rate}_2} = \sqrt{\frac{M_2}{M_1}}$
D.8	$N_t = N_0(0.5)^{t/k}$

2. Physical constants and unit conversions

Avogadro's constant (L or 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 = $2.27 \times 10^{-2} \text{ m}^3 \text{ mol}^{-1} = 22.7 \text{ dm}^3 \text{ mol}^{-1}$

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

STP conditions = 273 K and 100 kPa

SATP conditions = 298 K and 100 kPa

Speed of light = $3.00 \times 10^8 \text{ ms}^{-1}$

Specific heat capacity of water = $4.18 \text{ kJ kg}^{-1} \text{ K}^{-1} = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

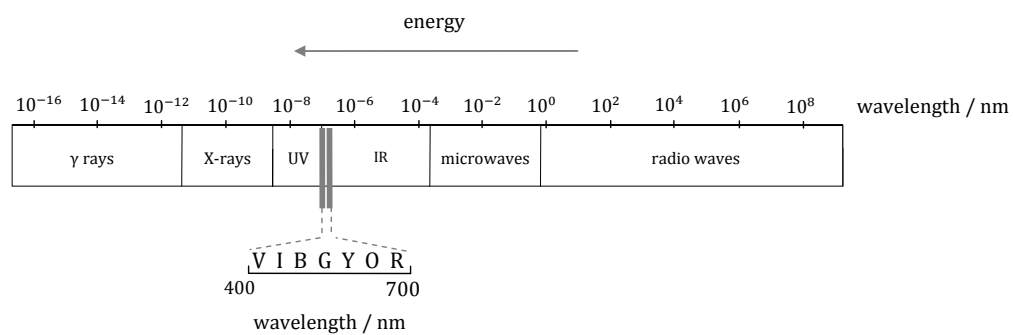
Planck's constant (h) = $6.63 \times 10^{-34} \text{ J s}$

Faraday's constant (F) = $9.65 \times 10^4 \text{ C mol}^{-1}$

Ionic product constant for water (K_w) = $1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K

$1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$

3. The electromagnetic spectrum



4. Fundamental particles

	Proton	Neutron	Electron
Mass (kg)	1.672622×10^{-27}	1.674927×10^{-27}	9.109383×10^{-31}
Charge (C)	1.602189×10^{-19}	0	$-1.602189 \times 10^{-19}$



5. 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
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
lutetium	Lu	71
magnesium	Mg	12
manganese	Mn	25

Element	Symbol	Atomic number
meitnerium	Mt	109
mendelevium	Md	101
mercury	Hg	80
molybdenum	Mo	42
neodymium	Nd	60
neon	Ne	10
neptunium	Np	93
nickel	Ni	28
niobium	Nb	41
nitrogen	N	7
nobelium	No	102
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
roentgenium	Rg	111
rubidium	Rb	37

Element	Symbol	Atomic number
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
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

6. 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	<div>Atomic number</div> <div>Element</div> <div>Relative atomic mass</div>																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
2	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
3	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 83.90					
	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					
4	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 Uut (286)	114 Uuq (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294)	118 Uuo (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)						

7. Melting points and boiling points of the elements (at 101.325 kPa)

−259.2 H −252.9																	<div>Melting point (°C)</div> <div>Element</div> <div>Boiling point (°C)</div>								<div>2077 B 4000</div> <div>3500 C 4827</div> <div>−210.0 N −195.8</div> <div>−218.8 O −183.0</div> <div>−219.7 F −188.1</div> <div>−248.6 Ne −246.0</div>	
180.5 Li 1342	1287 Be 2468																									
97.79 Na 882.9	650.0 Mg 1090																									
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																								

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

1312 −73 H 2.2	<div>First ionization energy (kJ mol^{−1})</div> <div>Electron affinity (kJ mol^{−1}) (2nd EA / kJ mol^{−1})</div> <div>Element</div> <div>Electronegativity</div>																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
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 2.6						
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																					

9. Atomic and ionic radii of the elements

32 H	<div>Atomic radius (10⁻¹² m)</div> <div>Element</div> <div>Ionic radius (10⁻¹² m)</div>																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															

10. Covalent bond lengths

Single bonds ($10^{-12}\text{m} = \text{pm}$)

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

Multiple bonds ($10^{-12}\text{m} = \text{pm}$)

C=C	134	C≡N	116	N≡N	110
C≡C	120	C=O	122	N=O	114
C=C (in benzene)	140	C=S	156	O=O	121
C=N	130	N=N	125	S=S	189

11. Bond enthalpies and average bond enthalpies at 298 K

Single bonds (kJ mol^{-1})

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

Multiple bonds (kJ mol^{-1})

C=C 614	C \equiv N 890	N \equiv N 945
C \equiv C 839	C=O 804	N=O 587
C \equiv C 507 (in benzene)	C=S 536	O=O 498
C=N 615	N=N 470	S=S 429

12. Selected compounds—thermodynamic data

Substance	Formula	State	ΔH_f° (kJ mol ⁻¹)	ΔG_f° (kJ mol ⁻¹)	S° (J K ⁻¹ mol ⁻¹)
methane	CH ₄	g	-74.0	-50.0	+186
ethane	C ₂ H ₆	g	-84.0	-32.0	+230
propane	C ₃ H ₈	g	-105	-24.0	+270
butane	C ₄ H ₁₀	g	-126	-17.0	+310
pentane	C ₅ H ₁₂	l	-173		
hexane	C ₆ H ₁₄	l	-199		
ethene	C ₂ H ₄	g	+52.0	+68.0	+220
propene	C ₃ H ₆	g	+20.0	+62.0	+267
but-1-ene	C ₄ H ₈	g	+0.10	+71.0	+306
<i>cis</i> -but-2-ene	C ₄ H ₈	g	-7.0	+66.0	+301
<i>trans</i> -but-2-ene	C ₄ H ₈	g	-11.0	+63.0	+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	+49.0	+125	+173
methylbenzene	C ₆ H ₅ CH ₃	l	+12.0		
ethylbenzene	C ₆ H ₅ CH ₂ CH ₃	l	-12.0		
phenylethene	C ₆ H ₅ CHCH ₂	l	+104		
chloromethane	CH ₃ Cl	g	-82.0	-58.0	+235
dichloromethane	CH ₂ Cl ₂	l	-124		+178
trichloromethane	CHCl ₃	l	-134	-74.0	+202
bromomethane	CH ₃ Br	g	-36.0	-26.0	+246
iodomethane	CH ₃ I	l	-14.0		+163
chloroethane	C ₂ H ₅ Cl	g	-137	-53.0	
bromoethane	C ₂ H ₅ Br	l	-90.0	-26.0	+199
chlorobenzene	C ₆ H ₅ Cl	l	+11.0		
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	+32.0	+243
water	H ₂ O	l	-285.8	-237.1	+70.0
steam	H ₂ O	g	-241.8	-228.6	+188.8
carbon monoxide	CO	g	-110.5	-137.2	+197.7
carbon dioxide	CO ₂	g	-393.5	-394.4	+213.8
hydrogen bromide	HBr	g	-36.3	-53.4	+198.7
hydrogen chloride	HCl	g	-92.3	-95.3	+186.9
hydrogen fluoride	HF	g	-273.3	-275.4	+173.8
hydrogen iodide	HI	g	+26.5	+1.7	+206.6

13. Enthalpies of combustion

The values of the molar enthalpy of combustion (ΔH_c^\ominus) in the following table refer to a temperature of 298 K and a pressure of 1.00×10^5 Pa.

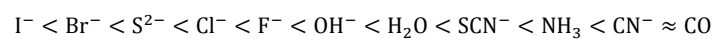
Substance	Formula	State	ΔH_c^\ominus (kJ mol ⁻¹)	Substance	Formula	State	ΔH_c^\ominus (kJ mol ⁻¹)
hydrogen	H ₂	g	-286	propan-1-ol	C ₃ H ₇ OH	l	-2021
sulfur	S	s	-297	butan-1-ol	C ₄ H ₉ OH	l	-2676
carbon (graphite)	C	s	-394	cyclohexanol	C ₆ H ₁₁ OH	s	-3728
carbon monoxide	CO	g	-283	phenol	C ₆ H ₅ OH	s	-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

14. Common oxidation numbers of the 3d ions

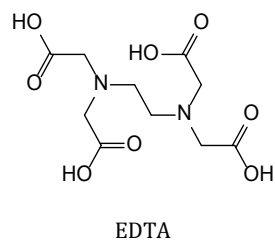
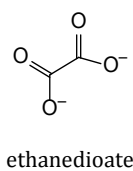
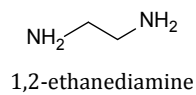
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
								+1	
	+2	+2	+2	+2	+2	+2	+2	+2	+2
+3	+3	+3	+3	+3	+3	+3			
	+4	+4		+4					
		+5							
			+6	+6					
				+7					

15. Spectrochemical series

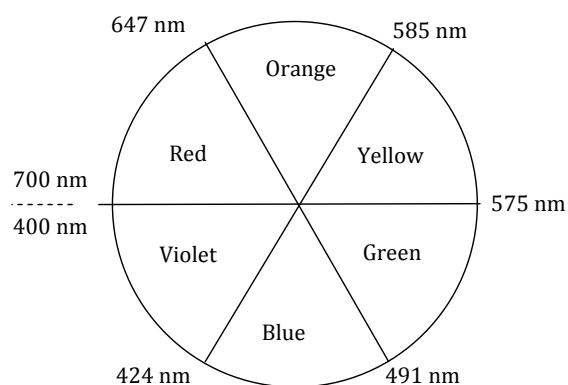
Ligands can be arranged in a spectrochemical series according to the energy difference they produce between the two sets of d-orbitals in an octahedral complex.



16. Ligands



17. Colour wheel



18. Lattice enthalpies at 298 K (experimental values)

The lattice enthalpy values ($\Delta H_{\text{lattice}}^{\circ}$) given 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.

Experimental values

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

Alkali metal halides	$\Delta H_{\text{lattice}}^{\circ}$ (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	$\Delta H_{\text{lattice}}^{\circ}$ (kJ mol ⁻¹)	Other substances	$\Delta H_{\text{lattice}}^{\circ}$ (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		

19. Enthalpies of aqueous solutions

Solute	$\Delta H_{\text{sol}}^{\circ}$ (kJ mol ⁻¹)	Solute	$\Delta H_{\text{sol}}^{\circ}$ (kJ mol ⁻¹)
NH ₄ Cl	+14.78	KCl	+17.22
NH ₄ NO ₃	+25.69	KBr	+19.87
LiF	+4.73	KI	+20.33
LiCl	-37.03	RbF	-26.11
LiBr	-48.83	RbCl	+17.28
LiI	-63.30	RbBr	+21.88
NaF	+0.91	RbI	+25.10
NaCl	+3.88	CsF	-36.86
NaBr	-0.60	CsCl	+17.78
NaI	-7.53	CsBr	+25.98
KF	-17.73	CsI	+33.35

20. Enthalpies of hydration

Cations	$\Delta H_{\text{hyd}}^{\circ}$ (kJ mol ⁻¹)	Anions	$\Delta H_{\text{hyd}}^{\circ}$ (kJ mol ⁻¹)
Li ⁺	-538	F ⁻	-504
Na ⁺	-424	Cl ⁻	-359
K ⁺	-340	Br ⁻	-328
Rb ⁺	-315	I ⁻	-287
Cs ⁺	-291	ClO ₃ ⁻	-331
Be ²⁺	-2524	BrO ₃ ⁻	-358
Mg ²⁺	-1963	IO ₃ ⁻	-446
Ca ²⁺	-1616	ClO ₄ ⁻	-205
Sr ²⁺	-1483	OH ⁻	-519
Ba ²⁺	-1346	CN ⁻	-341
Ra ²⁺	-1335	NO ₃ ⁻	-316
Al ³⁺	-4741	HCO ₃ ⁻	-383
Ga ³⁺	-4745	CO ₃ ²⁻	-1486
In ³⁺	-4171	HSO ₄ ⁻	-362
Tl ³⁺	-4163	SO ₄ ²⁻	-1099
Tl ⁺	-346	PO ₄ ³⁻	-2921
Sn ²⁺	-1587		
Pb ²⁺	-1523		

21. Strengths of organic acids and bases

The acid strengths in the following tables are given in terms of pK_a values, where $pK_a = -\log_{10}K_a$.

The dissociation constant K_a values are for aqueous solutions at 298 K. Base strengths are given in terms of pK_b values.

Carboxylic acids

Name	Formula	pK_a
methanoic	HCOOH	3.75
ethanoic	CH ₃ COOH	4.76
propanoic	CH ₃ CH ₂ COOH	4.87
butanoic	CH ₃ (CH ₂) ₂ COOH	4.83
2-methylpropanoic	(CH ₃) ₂ CHCOOH	4.84
pentanoic	CH ₃ (CH ₂) ₃ COOH	4.83
2,2-dimethylpropanoic	(CH ₃) ₃ CCOOH	5.03
benzoic	C ₆ H ₅ COOH	4.20
phenylethanoic	C ₆ H ₅ CH ₂ COOH	4.31

Halogenated carboxylic acids

Name	Formula	pK_a
chloroethanoic	CH ₂ ClCOOH	2.87
dichloroethanoic	CHCl ₂ COOH	1.35
trichloroethanoic	CCl ₃ COOH	0.66
fluoroethanoic	CH ₂ FCOOH	2.59
bromoethanoic	CH ₂ BrCOOH	2.90
iodoethanoic	CH ₂ ICOOH	3.18

Phenols

Name	Formula	p <i>K</i> _a
phenol	C ₆ H ₅ OH	9.99
2-nitrophenol	O ₂ NC ₆ H ₄ OH	7.23
3-nitrophenol	O ₂ NC ₆ H ₄ OH	8.36
4-nitrophenol	O ₂ NC ₆ H ₄ OH	7.15
2,4-dinitrophenol	(O ₂ N) ₂ C ₆ H ₃ OH	4.07
2,4,6-trinitrophenol	(O ₂ N) ₃ C ₆ H ₂ OH	0.42

Alcohols

Name	Formula	p <i>K</i> _a
methanol	CH ₃ OH	15.5
ethanol	C ₂ H ₅ OH	15.5

Amines

Name	Formula	p <i>K</i> _b
ammonia	NH ₃	4.75
methylamine	CH ₃ NH ₂	3.34
ethylamine	CH ₃ CH ₂ NH ₂	3.35
dimethylamine	(CH ₃) ₂ NH	3.27
trimethylamine	(CH ₃) ₃ N	4.20
diethylamine	(C ₂ H ₅) ₂ NH	3.16
triethylamine	(C ₂ H ₅) ₃ N	3.25
phenylamine	C ₆ H ₅ NH ₂	9.13

22. Acid-base indicators

Indicator	pK_a	pH range	Colour change	
			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

23. Values of the ionization constant of water

Temperature (°C)	K_w value
0	0.113×10^{-14}
5	0.185×10^{-14}
10	0.292×10^{-14}
15	0.453×10^{-14}
20	0.684×10^{-14}
25	1.00×10^{-14}
30	1.47×10^{-14}
35	2.09×10^{-14}
40	2.92×10^{-14}
45	4.02×10^{-14}
50	5.43×10^{-14}
55	7.24×10^{-14}
60	9.55×10^{-14}
65	12.4×10^{-14}
70	15.9×10^{-14}
75	20.1×10^{-14}
80	25.2×10^{-14}
85	31.3×10^{-14}
90	38.3×10^{-14}
95	46.6×10^{-14}
100	56.0×10^{-14}

24. Standard electrode potentials at 298 K

Oxidized species	Reduced species	E^\ominus (V)
$\text{Li}^+(\text{aq}) + \text{e}^-$	$\text{Li}(\text{s})$	-3.04
$\text{K}^+(\text{aq}) + \text{e}^-$	$\text{K}(\text{s})$	-2.93
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Ca}(\text{s})$	-2.87
$\text{Na}^+(\text{aq}) + \text{e}^-$	$\text{Na}(\text{s})$	-2.71
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Mg}(\text{s})$	-2.37
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^-$	$\text{Al}(\text{s})$	-1.66
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Mn}(\text{s})$	-1.18
$\text{H}_2\text{O}(\text{l}) + \text{e}^-$	$\frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^-(\text{aq})$	-0.83
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Zn}(\text{s})$	-0.76
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Fe}(\text{s})$	-0.45
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Ni}(\text{s})$	-0.26
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Sn}(\text{s})$	-0.14
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Pb}(\text{s})$	-0.13
$\text{H}^+(\text{aq}) + \text{e}^-$	$\frac{1}{2}\text{H}_2(\text{g})$	0.00

Oxidized species	Reduced species	E^\ominus (V)
$\text{Cu}^{2+}(\text{aq}) + \text{e}^-$	$\text{Cu}^+(\text{aq})$	+0.15
$\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^-$	$\text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	+0.17
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$	$\text{Cu}(\text{s})$	+0.34
$\frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^-$	$2\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^+(\text{aq}) + \text{e}^-$	$\text{Cu}(\text{s})$	+0.52
$\frac{1}{2}\text{I}_2(\text{s}) + \text{e}^-$	$\text{I}^-(\text{aq})$	+0.54
$\text{Fe}^{3+}(\text{aq}) + \text{e}^-$	$\text{Fe}^{2+}(\text{aq})$	+0.77
$\text{Ag}^+(\text{aq}) + \text{e}^-$	$\text{Ag}(\text{s})$	+0.80
$\frac{1}{2}\text{Br}_2(\text{l}) + \text{e}^-$	$\text{Br}^-(\text{aq})$	+1.09
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}_2(\text{aq}) + 2\text{e}^-$	$\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^-$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.36
$\frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^-$	$\text{Cl}^-(\text{aq})$	+1.36
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^-$	$\text{Mn}^{2+} + 4\text{H}_2\text{O}(\text{l})$	+1.51
$\frac{1}{2}\text{F}_2(\text{g}) + \text{e}^-$	$\text{F}^-(\text{aq})$	+2.87

25. Activity series

Increasing activity	
↑	Li
	Cs
	Rb
	K
	Ba
	Sr
	Ca
	Na
	Mg
	Be
	Al
	C
	Zn
	Cr
	Fe
	Cd
	Co
	Ni
	Sn
	Pb
	H
	Sb
	As
	Bi
	Cu
	Ag
	Pd
	Hg
	Pt
	Au

26. Infrared data

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

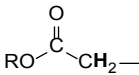
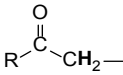
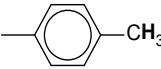
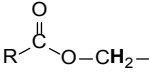
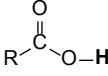
Bond	Organic molecules	Wavenumber (cm^{-1})	Intensity
C-I	iodoalkanes	490–620	strong
C-Br	bromoalkanes	500–600	strong
C-Cl	chloroalkanes	600–800	strong
C-F	fluoroalkanes	1000–1400	strong
C-O	alcohols, esters, ethers	1050–1410	strong
C=C	alkenes	1620–1680	medium-weak; multiple bands
C=O	aldehydes, ketones,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

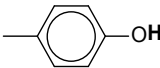


27. ^1H NMR data

Typical proton chemical shift values (δ) relative to tetramethylsilane (TMS) = 0 .

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

These values may vary in different solvents and conditions.

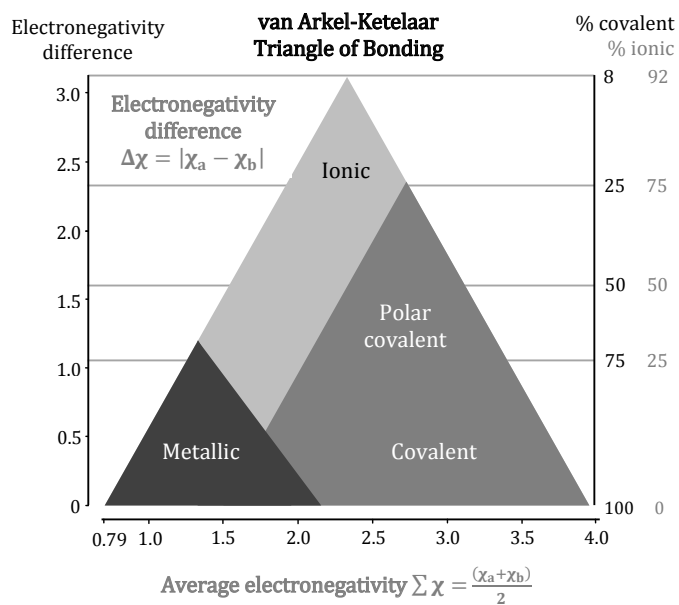
Type of proton	Chemical shift (ppm)
$-\text{CH}_3$	0.9–1.0
$-\text{CH}_2-\text{R}$	1.3–1.4
$-\text{R}_2\text{CH}$	1.5
	2.0–2.5
	2.2–2.7
	2.5–3.5
$-\text{C}\equiv\text{C}-\text{H}$	1.8–3.1
$-\text{CH}_2-\text{Hal}$	3.5–4.4
$\text{R}-\text{O}-\text{CH}_2-$	3.3–3.7
	3.7–4.8
	9.0–13.0
$\text{R}-\text{O}-\text{H}$	1.0–6.0
$-\text{HC}=\text{CH}_2$	4.5–6.0

Type of proton	Chemical shift (ppm)
	4.0–12.0
	6.9–9.0
	9.4–10.0





28. Mass spectral fragments lost




Mass lost	Fragment lost
15	CH ₃
17	OH
18	H ₂ O
28	CH ₂ =CH ₂ , C=O
29	CH ₃ CH ₂ , CHO
31	CH ₃ O
45	COOH

29. Triangular bonding diagram

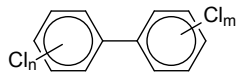


30. Resin identification codes

Resin Identification Code (RIC)	Plastic types
 PETE	polyethylene terephthalate
 HDPE	high-density polyethylene
 PVC	polyvinyl chloride
 LDPE	low-density polyethylene

Resin Identification Code (RIC)	Plastic types
 PP	polypropylene
 PS	polystyrene
 OTHER	other

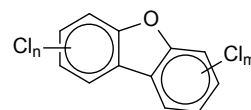
31. Representations of some materials molecules



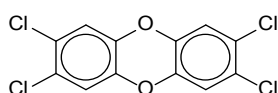
polychlorinated biphenyls



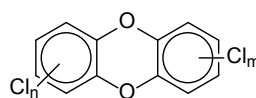
1,4-dioxin



polychlorinated dibenzofuran



2,3,7,8-tetrachlorodibenzodioxin

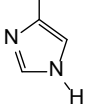



polychlorinated dibenzo-*p*-dioxin

32. Solubility product constants at 298 K

Compound	K_{sp}
BaCO ₃	2.58×10^{-9}
Ba(OH) ₂ · 8H ₂ O	2.55×10^{-4}
BaSO ₄	1.08×10^{-10}
CdCO ₃	1.0×10^{-12}
Cd(OH) ₂	7.2×10^{-15}
PbCO ₃	7.40×10^{-14}
Pb(OH) ₂	1.43×10^{-20}
PbSO ₄	2.53×10^{-8}
Hg ₂ CO ₃	3.6×10^{-17}
Hg ₂ SO ₄	6.5×10^{-7}
NiCO ₃	1.42×10^{-7}
Ni(OH) ₂	5.48×10^{-16}
Ag ₂ CO ₃	8.46×10^{-12}
Ag ₂ SO ₄	1.20×10^{-5}
ZnCO ₃	1.46×10^{-10}
Zn(OH) ₂	3.0×10^{-17}

33. 2-amino acids

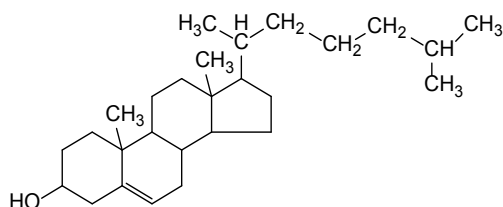
Common name	Symbol	Structural formula	pH of isoelectric point
alanine	Ala	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_3 \end{array}$	6.0
arginine	Arg	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}-\text{C}-\text{NH}_2 \\ \\ \text{NH} \end{array}$	10.8
asparagine	Asn	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{O} \end{array}$	5.4
aspartic acid	Asp	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{COOH} \end{array}$	2.8
cysteine	Cys	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{SH} \end{array}$	5.1
glutamic acid	Glu	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{CH}_2-\text{COOH} \end{array}$	3.2
glutamine	Gln	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{O} \end{array}$	5.7
glycine	Gly	$\text{H}_2\text{N}-\text{CH}_2-\text{COOH}$	6.0
histidine	His	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2 \\ \\ \text{N} \end{array}$ 	7.6
isoleucine	Ile	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{H}_3\text{C}-\text{CH}-\text{CH}_2-\text{CH}_3 \end{array}$	6.0
leucine	Leu	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2 \\ \\ \text{H}_3\text{C}-\text{CH}-\text{CH}_3 \end{array}$	6.0

Common name	Symbol	Structural formula	pH of isoelectric point
lysine	Lys	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}_2 \end{array}$	9.7
methionine	Met	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{CH}_2-\text{S}-\text{CH}_3 \end{array}$	5.7
phenylalanine	Phe	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2 \\ \\ \text{C}_6\text{H}_5 \end{array}$	5.5
proline	Pro		6.3
serine	Ser	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2-\text{OH} \end{array}$	5.7
threonine	Thr	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{H}_3\text{C}-\text{CH}-\text{OH} \end{array}$	5.6
tryptophan	Trp	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2 \\ \\ \text{C}_8\text{H}_6\text{N} \end{array}$	5.9
tyrosine	Tyr	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{CH}_2 \\ \\ \text{C}_6\text{H}_4 \\ \\ \text{OH} \end{array}$	5.7
valine	Val	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}-\text{COOH} \\ \\ \text{H}_3\text{C}-\text{CH}-\text{CH}_3 \end{array}$	6.0

34. Lipids, carbohydrates and nucleotide components

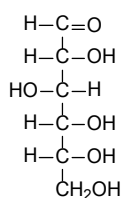
Lipids

Octanoic acid	$\text{CH}_3(\text{CH}_2)_6\text{COOH}$
Lauric acid	$\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$
Palmitic acid	$\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$
Stearic acid	$\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$
Oleic acid	$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$
Linoleic acid	$\text{CH}_3(\text{CH}_2)_4(\text{CH}=\text{CHCH}_2)_2(\text{CH}_2)_6\text{COOH}$
α -Linolenic acid	$\text{CH}_3\text{CH}_2(\text{CH}=\text{CHCH}_2)_3(\text{CH}_2)_6\text{COOH}$

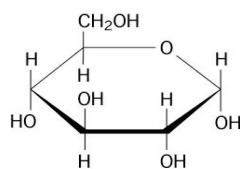


cholesterol

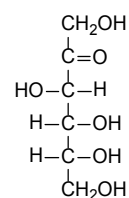
Carbohydrates



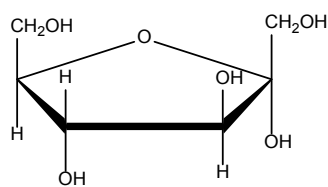
straight chain glucose



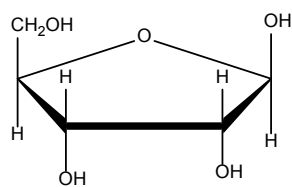
α -glucose



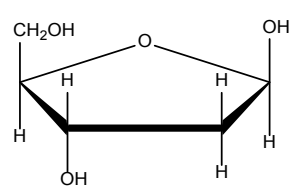
straight chain fructose



fructose

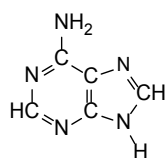


ribose

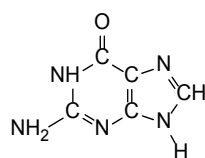


deoxyribose

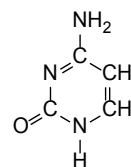
Nitrogenous bases



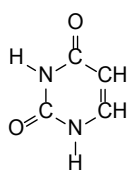
adenine



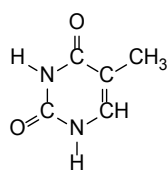
guanine



cytosine



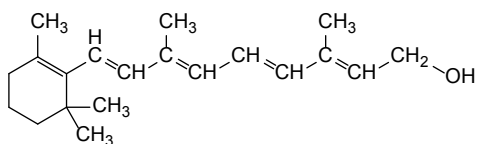
uracil



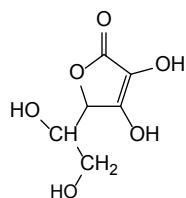
thymine

35. Vitamins and pigments

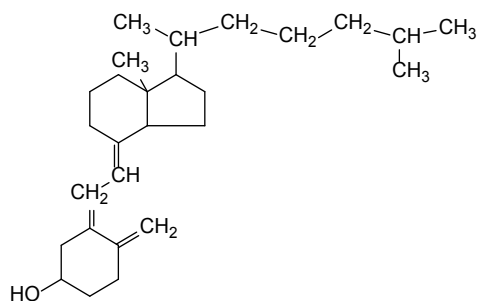
Vitamins



retinol (vitamin A)

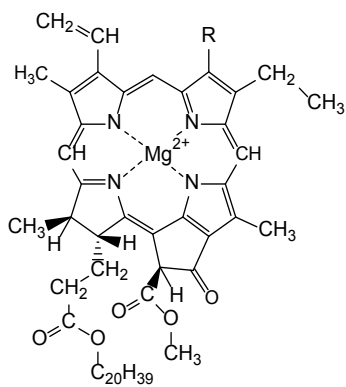


ascorbic acid (vitamin C)

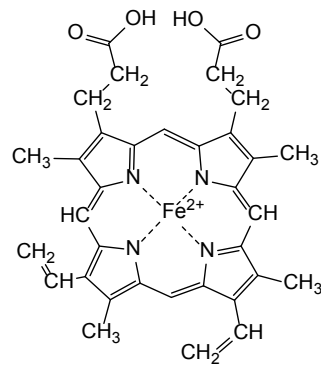


vitamin D (D3)

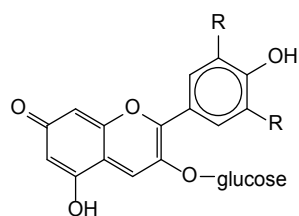
Pigments



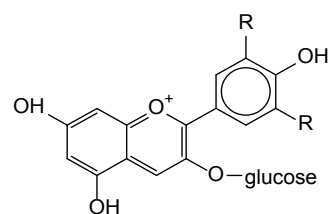
chlorophyll



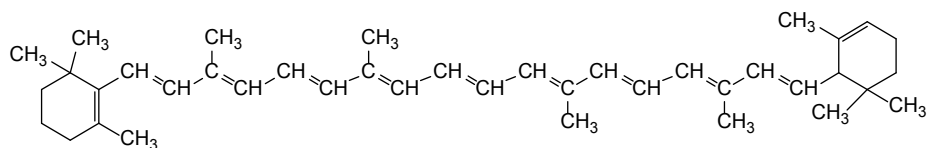
heme B



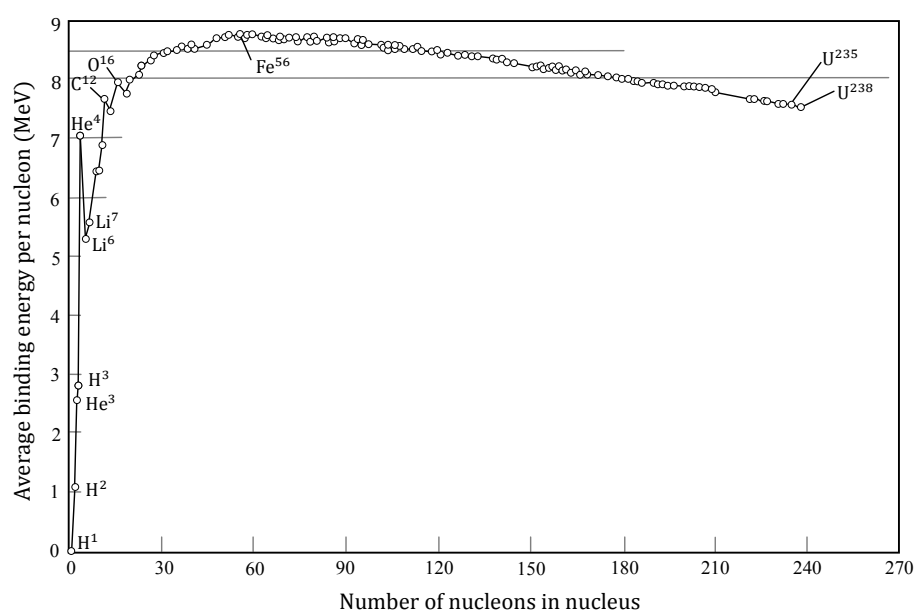
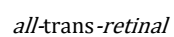
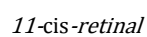
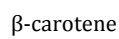
quinoidal base (blue)



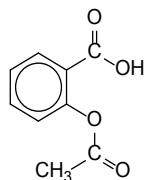
flavylium cation (red)



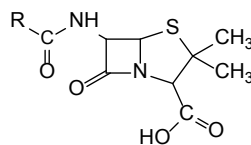
α -carotene



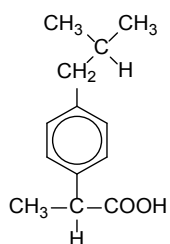
37. Representations of some medicinal molecules



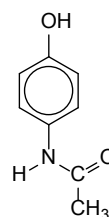
aspirin



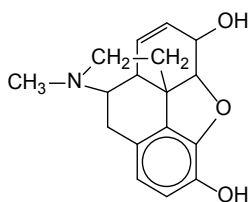
penicillin (general structure)



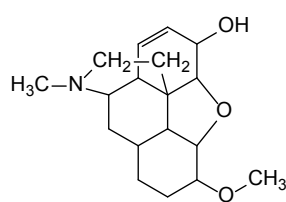
ibuprofen



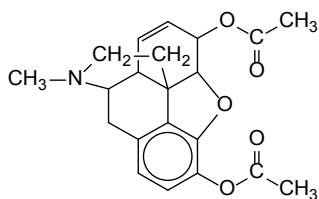
paracetamol (acetaminophen)



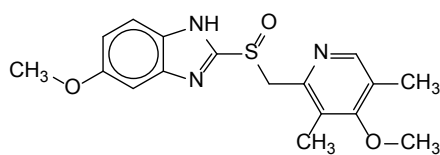
morphine



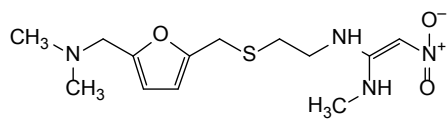
codeine



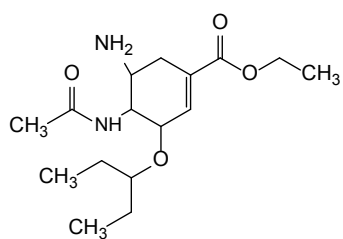
diamorphine (heroin)



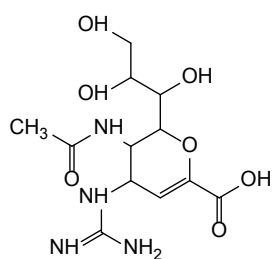
omeprazole



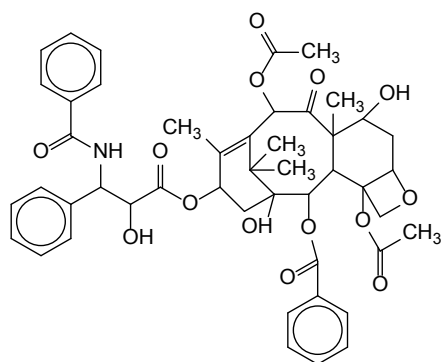
ranitidine



oseltamivir



zanamivir



taxol

38. References

Data in sections 9, 10, 11, 12, 13, 22, 26 and 27 was taken fully or in part from:

Aylward, G and Findlay, T. 2008. *SI chemical data*. (5th edition). Queensland, Australia. John Wiley & Sons.

Data in section 20 reproduced by permission of The Royal Society of Chemistry.

Barret, J. 2003. *Inorganic chemistry in aqueous solution*. London, UK. Royal Society of Chemistry.

Data in section 13 was taken in part from:

Burgess, DR. 2012. "Thermochemical Data". *NIST Chemistry WebBook, NIST Standard Reference Database*. Number 69. <http://webbook.nist.gov>.

Data in sections 7, 8, 9, 12, 13, 18, 19, 21, 23, 24, 28, 32, 33 was taken fully or in part from:

Haynes, WM, (ed). 2012. *CRC Handbook of chemistry and physics*. (93rd edition). Boca Raton, US. CRC Press.

Data in section 29 can be found in the following source:

Leach, MR. 2013. *Timeline of structural theory*. 04 January 2013.
http://www.meta-synthesis.com/webbook/30_timeline/timeline.html.