International Baccalaureate
Baccalauréat International
Bachillerato Internacional

Diploma Programme

Chemistry data booklet

First assessment 2016

Published February 2014

Contents

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	Topic	Equation
1.3	$PV = nR$	A.5	$\%\ \text{Atom Economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100\%$
2.2 and C.4	$c = v\lambda$	A.8	$n\lambda = 2dsin\theta$
5.1	$q = mc\Delta T$	B.7	$pH = pK_a + \log\left(\frac{[A^-]}{[HA]}\right)$
8.3	$pH = -\log_{10}[H_3O^+]$ or $pH = -\log_{10}[H^+]$	B.7	$\log_{10}\frac{I_0}{I} = \varepsilon lc$
12.1	$E = hv$	C.1	$\text{Energy density} = \frac{\text{energy released from fuel}}{\text{volume of fuel consumed}}$
15.2	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$	C.1	$\text{Specific energy} = \frac{\text{energy released from fuel}}{\text{mass of fuel consumed}}$
16.2	$k = Ae^{\frac{-E_a}{RT}}$	C.3	$N = N_0 e^{-\lambda t}$
16.2	$\ln k = \frac{-E_a}{RT} + \ln A$	C.3 and D.8	$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$
16.2	$\ln\frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$	C.6	$E = E^0 - \left(\frac{RT}{nF}\right)\ln Q$
17.1	$\Delta G^\circ = -RT\ln K$	C.7	$\frac{\text{Rate}_1}{\text{Rate}_2} = \sqrt{\frac{M_2}{M_1}}$
19.1	$\Delta G^\circ = -nFE^\circ$	D.8	$N_t = N_0(0.5)^{t/k}$

2. Physical constants and unit conversions

Avogadro's constant (L or N_A) = 6.02×10^{23} mol^{-1}

Gas constant (R) = 8.31 J K^{-1} mol^{-1}

Molar volume of an ideal gas at STP = 2.27×10^{-2} m^3 mol^{-1} (= 22.7 dm^3 mol^{-1})

1 dm^3 = 1 litre = 1×10^{-3} m^3 = 1×10^3 cm^3

STP conditions = 273 K and 100 kPa

SATP conditions = 298 K and 100 kPa

Speed of light = 3.00×10^8 ms^{-1}

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

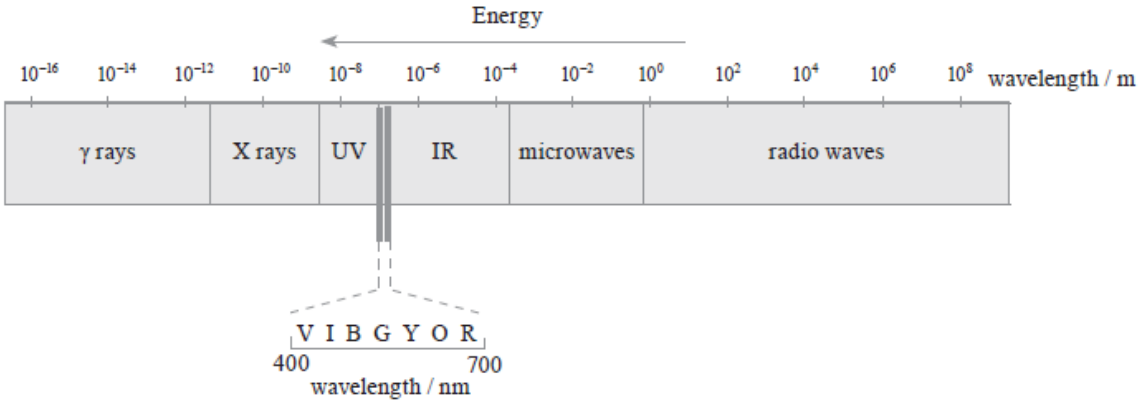
Planck's constant (h) = 6.63×10^{-34} J s

Faraday's constant (F) = 96 500 C mol^{-1}

Ionic product constant for water (K_w) = 1.00×10^{-14} at 298 K

1 amu = 1.66×10^{-27} 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	1.602189×10^{-19}

5. Names of the elements

Element	Symbol	Atomic number	Element	Symbol	Atomic number
actinium	Ac	89	mendelevium	Md	101
aluminium	Al	13	mercury	Hg	80
americium	Am	95	molybdenum	Mo	42
antimony	Sb	51	neodymium	Nd	60
argon	Ar	18	neon	Ne	10
arsenic	As	33	neptunium	Np	93
astatine	At	85	nickel	Ni	28
barium	Ba	56	niobium	Nb	41
berkelium	Bk	97	nitrogen	N	7
beryllium	Be	4	nobelium	No	102
bismuth	Bi	83	osmium	Os	76
bohrium	Bh	107	oxygen	O	8
boron	B	5	palladium	Pd	46
bromine	Br	35	phosphorus	P	15
cadmium	Cd	48	platinum	Pt	78
caesium	Cs	55	plutonium	Pu	94
calcium	Ca	20	polonium	Po	84
californium	Cf	98	potassium	K	19
carbon	C	6	praseodymium	Pr	59
cerium	Ce	58	promethium	Pm	61
chlorine	Cl	17	protactinium	Pa	91
chromium	Cr	24	radium	Ra	88
cobalt	Co	27	radon	Rn	86
copernicium	Cn	112	rhenium	Re	75
copper	Cu	29	rhodium	Rh	45
curium	Cm	96	roentgenium	Rg	111
darmstadtium	Ds	110	rubidium	Rb	37
dubnium	Db	105	ruthenium	Ru	44
dysprosium	Dy	66	rutherfordium	Rf	104
einsteinium	Es	99	samarium	Sm	62
erbium	Er	68	scandium	Sc	21
europium	Eu	63	seaborgium	Sg	106
fermium	Fm	100	selenium	Se	34
fluorine	F	9	silicon	Si	14
francium	Fr	87	silver	Ag	47

Element	Symbol	Atomic number	Element	Symbol	Atomic number
gadolinium	Gd	64	sodium	Na	11
gallium	Ga	31	strontium	Sr	38
germanium	Ge	32	sulfur	S	16
gold	Au	79	tantalum	Ta	73
hafnium	Hf	72	technetium	Tc	43
hassium	Hs	108	tellurium	Te	52
helium	He	2	terbium	Tb	65
holmium	Ho	67	thallium	Tl	81
hydrogen	H	1	thorium	Th	90
indium	In	49	thulium	Tm	69
iodine	I	53	tin	Sn	50
iridium	Ir	77	titanium	Ti	22
iron	Fe	26	tungsten	W	74
krypton	Kr	36	uranium	U	92
lanthanum	La	57	vanadium	V	23
lawrencium	Lr	103	xenon	Xe	54
lead	Pb	82	ytterbium	Yb	70
lithium	Li	3	yttrium	Y	39
lutetium	Lu	71	zinc	Zn	30
magnesium	Mg	12	zirconium	Zr	40
manganese	Mn	25			
meitnerium	Mt	109			

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																	2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01					Atomic number **Element** Relative atomic mass						5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.90
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.20	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	89 ‡ **Ac** (227)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (269)	107 **Bh** (270)	108 **Hs** (269)	109 **Mt** (278)	110 **Ds** (281)	111 **Rg** (281)	112 **Cn** (285)	113 **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				Melting point (°C) **Element** Boiling point (°C)													**He** −268.9
180.5 **Li** 1342	1287 **Be** 2468											2077 **B** 4000	3500 **C** 4827	−210.0 **N** −195.8	−218.8 **O** −183.0	−219.7 **F** −188.1	−248.6 **Ne** −246.0
97.8 **Na** 882.9	650 **Mg** 1090											660.3 **Al** 2519	1414 **Si** 3265	44.2 **P** 280.5	115.2 **S** 444.6	−101.5 **Cl** −34.0	−189.3 **Ar** −185.8
63.5 **K** 759	842 **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	1084.6 **Cu** 2560	419.5 **Zn** 907	29.8 **Ga** 2229	938.2 **Ge** 2833	817 **As** 616	220.8 **Se** 685	−7.2 **Br** 58.8	−157.4 **Kr** −153.4
39.3 **Rb** 688	777 **Sr** 1377	1522 **Y** 3345	1854 **Zr** 4406	2477 **Nb** 4741	2622 **Mo** 4639	2157 **Tc** 4262	2333 **Ru** 4147	1963 **Rh** 3695	1554.8 **Pd** 2963	961.8 **Ag** 2162	321.1 **Cd** 767	156.6 **In** 2027	231.9 **Sn** 2586	630.6 **Sb** 1587	449.5 **Te** 988	113.7 **I** 184.4	−111.8 **Xe** −108.1
28.5 **Cs** 671	727 **Ba** 1845	920 **La** 3464	2233 **Hf** 4600	3017 **Ta** 5455	3414 **W** 5555	3453 **Re** 5900	3033 **Os** 5008	2446 **Ir** 4428	1768.2 **Pt** 3825	1064.2 **Au** 2836	−38.8 **Hg** 356.6	304 **Tl** 1473	327.5 **Pb** 1749	271.4 **Bi** 1564	254 **Po** 962	302 **At**	−71 **Rn** −61.7
21 **Fr**	696 **Ra**	1050 **Ac** 3200															

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

1312 −73 **H** 2.2																	2372 **He**
520 −60 **Li** 1.0	900 **Be** 1.6											801 −27 **B** 2.0	1086 −122 **C** 2.6	1402 **N** 3.0	1314 −141 (+753) **O** 3.4	1681 −328 **F** 4.0	2081 **Ne**
496 −53 **Na** 0.9	738 **Mg** 1.3											578 −42 **Al** 1.6	787 −134 **Si** 1.9	1012 −72 **P** 2.2	1000 −200 (+545) **S** 2.6	1251 −349 **Cl** 3.2	1520 **Ar**
419 −48 **K** 0.8	590 −2 **Ca** 1.0	633 −18 **Sc** 1.4	659 −8 **Ti** 1.5	651 −51 **V** 1.6	653 −64 **Cr** 1.7	717 **Mn** 1.6	762 −15 **Fe** 1.8	760 −64 **Co** 1.9	737 −112 **Ni** 1.9	745 −119 **Cu** 1.9	906 **Zn** 1.6	579 −41 **Ga** 1.8	762 −119 **Ge** 2.0	944 −78 **As** 2.2	941 −195 **Se** 2.6	1140 −325 **Br** 3.0	1351 **Kr**
403 −47 **Rb** 0.8	549 −5 **Sr** 1.0	600 −30 **Y** 1.2	640 −41 **Zr** 1.3	652 −88 **Nb** 1.6	684 −72 **Mo** 2.2	702 −53 **Tc** 2.1	710 −101 **Ru** 2.2	720 −110 **Rh** 2.3	804 −54 **Pd** 2.2	731 −126 **Ag** 1.9	868 **Cd** 1.7	558 −29 **In** 1.8	709 −107 **Sn** 2.0	831 −101 **Sb** 2.0	869 −190 **Te** 2.1	1008 −295 **I** 2.7	1170 **Xe** 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															

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

Element

Electronegativity

9. Atomic and ionic radii of the elements

32 **H**				Atomic radius (10^{-12} m) **Element** Ionic radius/ (10^{-12} m)												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} m = 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} m = 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≡N	890	N≡N	945
C≡C	839	C=O	804	N=O	587
C ⁼⁼⁼ C (in benzene)	507	C=S	536	O=O	498
C=N	615	N=N	470	S=S	429

12. Selected compounds—thermodynamic data

Substance	Formula	State	$\Delta H_f^\ominus$ (kJ mol^{-1})	$\Delta G_f^\ominus$ (kJ mol^{-1})	$S^\ominus$ (J K^{-1} mol^{-1})
methane	CH_4	g	−74.0	−50.0	+186
ethane	C_2H_6	g	−84.0	−32.0	+230
propane	C_3H_8	g	−105	−24.0	+270
butane	C_4H_{10}	g	−126	−17.0	+310
pentane	C_5H_{12}	l	−173		
hexane	C_6H_{14}	l	−199		
ethene	C_2H_4	g	+52.0	+68.0	+220
propene	C_3H_6	g	+20.0	+62.0	+267
but-1-ene	C_4H_8	g	+0.10	+71.0	+306
cis-but-2-ene	C_4H_8	g	−7.0	+66.0	+301
trans-but-2-ene	C_4H_8	g	−11.0	+63.0	+297
ethyne	C_2H_2	g	+228	+211	+201
propyne	C_3H_4	g	+185	+194	+248
buta-1,3-diene	C_4H_6	g	+110	+151	+279
cyclohexane	C_6H_{12}	l	−156		
benzene	C_6H_6	l	+49.0	+125	+173
methylbenzene	$C_6H_5CH_3$	l	+12.0		
ethylbenzene	$C_6H_5CH_2CH_3$	l	−12.0		
phenylethene	$C_6H_5CHCH_2$	l	+104		
chloromethane	CH_3Cl	g	−82.0	−58.0	+235
dichloromethane	CH_2Cl_2	l	−124		+178
trichloromethane	$CHCl_3$	l	−134	−74.0	+202
bromomethane	CH_3Br	g	−36.0	−26.0	+246
iodomethane	CH_3I	l	−14.0		+163
chloroethane	C_2H_5Cl	g	−137	−53.0	
bromoethane	C_2H_5Br	l	−90.0	−26.0	+199
chlorobenzene	C_6H_5Cl	l	+11.0		
methanol	CH_3OH	l	−239	−167	+127
ethanol	C_2H_5OH	l	−278	−175	+161
phenol	C_6H_5OH	s	−165		+144
methanal	HCHO	g	−109	−102	+219
ethanal	CH_3CHO	g	−166	−133	+264
propanone	$(CH_3)_2CO$	l	−248		+200
methanoic acid	HCOOH	l	−425	−361	+129
ethanoic acid	CH_3COOH	l	−484	−390	+160
benzoic acid	C_6H_5COOH	s	−385		+168
methylamine	CH_3NH_2	g	−23	+32.0	+243
water	H_2O	l	−285.8	−237.1	+70.0

Substance	Formula	State	($kJ\ mol^{-1}$)	($kJ\ mol^{-1}$)	($J\ K^{-1}\ mol^{-1}$)
steam	H_2O	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°) 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° (kJ mol^{-1})	Substance	Formula	State	ΔH_c° (kJ mol^{-1})
hydrogen	H_2	g	−286	propan-1-ol	C_3H_7OH	1	−2021
sulfur	S	s	−297	butan-1-ol	C_4H_9OH	1	−2676
carbon (graphite)	C	s	−394	cyclohexanol	$C_6H_{11}OH$	s	−3728
carbon monoxide	CO	g	−283	phenol	C_6H_5OH	s	−3053
methane	CH_4	g	−891	ethoxyethane	$(C_2H_5)_2O$	l	−2724
ethane	C_2H_6	g	−1561	methanal	HCHO	g	−571
propane	C_3H_8	g	−2219	ethanal	CH_3CHO	g	−1167
butane	C_4H_{10}	g	−2878	benzaldehyde	C_6H_5CHO	l	−3525
pentane	C_5H_{12}	l	−3509	propanone	$(CH_3)_2CO$	l	−1790
hexane	C_6H_{14}	l	−4163	pentan-3-one	$(C_2H_5)_2CO$	l	−3100
octane	C_8H_{18}	l	−5470	phenylethanone	$CH_3COC_6H_5$	l	−4149
cyclohexane	C_6H_{12}	l	−3920	methanoic acid	HCOOH	l	−255
ethene	C_2H_4	g	−1411	ethanoic acid	CH_3COOH	l	−874
buta-1,3-diene	C_4H_6	g	−2541	benzoic acid	C_6H_5COOH	s	−3228
ethyne	C_2H_2	g	−1301	ethanedioic acid	$(COOH)_2$	s	−243
benzene	C_6H_6	l	−3268	ethyl ethanoate	$CH_3COOC_2H_5$	l	−2238
methylbenzene	$C_6H_5CH_3$	l	−3910	ethanamide	CH_3CONH_2	s	−1186
naphthalene	$C_{10}H_8$	s	−5156	methylamine	CH_3NH_2	g	−1086
chloroethane	C_2H_5Cl	g	−1413	phenylamine	$C_6H_5NH_2$	l	−3393
iodoethane	C_2H_5I	l	−1463	nitrobenzene	$C_6H_5NO_2$	l	−3088
trichloromethane	$CHCl_3$	l	−473	urea	$CO(NH_2)_2$	s	−633
methanol	CH_3OH	l	−726	glucose	$C_6H_{12}O_6$	s	−2803
ethanol	C_2H_5OH	l	−1367	sucrose	$C_{12}H_{22}O_{11}$	s	−5640

14. Common oxidation numbers of 3-D ions

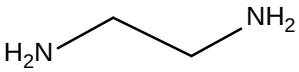
Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
								+1	
	+2	+2	+2	+2	+2	+2	+2	+2	+2
+3	+3	+3	+3	+3	+3	+3			
	+4	+4		+4					
		+5							
			+6	+6					
				+7					

15. Spectrochemical series

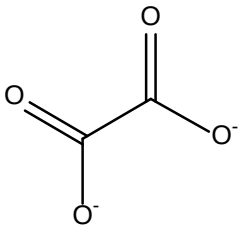
Ligands can be arranged in a spectrochemical series according to the energy difference they produce between the two sets of d-orbitals in an octahedral complex.

$$I^- < Br^- < S^{2-} < Cl^- < F^- < OH^- < H_2O < SCN^- < NH_3 < CN^- < CO$$

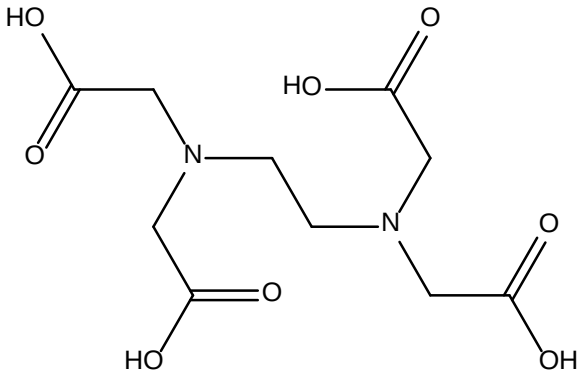
16. Ligands



ethylene diamine/1,2-ethanediamine

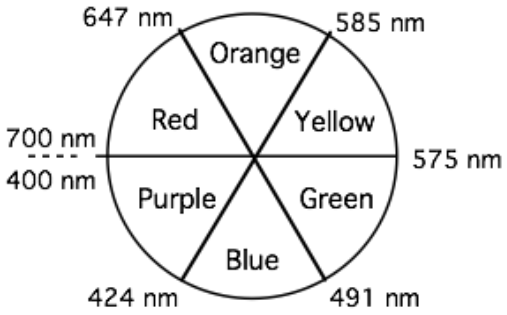


oxalate/ethanedioate



EDTA

17. Colour wheel



18. Lattice enthalpies at 298 K (experimental values)

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

Experimental values

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

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

Other substances	$\Delta H^{\circ}_{\text{lattice}}$ (kJ mol^{-1})	Other substances	$\Delta H^{\circ}_{\text{lattice}}$ (kJ mol^{-1})
CaF_2	2651	$CuCl_2$	2824
$BeCl_2$	3033	AgF	974
$MgCl_2$	2540	AgCl	918
$CaCl_2$	2271	AgBr	905
$SrCl_2$	2170	AgI	892
$BaCl_2$	2069		
MgO	3791		
CaO	3401		
SrO	3223		
BaO	3054		

19. Enthalpies of aqueous solutions

Solute	ΔH°_{sol} (kJ mol^{-1})	Solute	ΔH°_{sol} (kJ mol^{-1})
NH_4Cl	+14.78	KCl	+17.22
NH_4NO_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	ΔH°_{hyd}(kJ mol^{-1})	Anions	ΔH°_{hyd} (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_3COOH	4.76
propanoic	CH_3CH_2COOH	4.87
butanoic	$CH_3(CH_2)_2COOH$	4.83
2-methylpropanoic	$(CH_3)_2CHCOOH$	4.84
pentanoic	$CH_3(CH_2)_3COOH$	4.83
2,2-dimethylpropanoic	$(CH_3)_3CCOOH$	5.03
benzoic	C_6H_5COOH	4.20
phenylethanoic	$C_6H_5CH_2COOH$	4.31

Halogenated carboxylic acids

Name	Formula	pK_a
chloroethanoic	$CH_2ClCOOH$	2.87
dichloroethanoic	$CHCl_2COOH$	1.35
trichloroethanoic	CCl_3COOH	0.66
fluoroethanoic	CH_2FCOOH	2.59
bromoethanoic	$CH_2BrCOOH$	2.90
iodoethanoic	CH_2ICOOH	3.18

Phenols

Name	Formula	pK_a
phenol	C_6H_5OH	9.99
2-nitrophenol	$O_2NC_6H_4OH$	7.23
3-nitrophenol	$O_2NC_6H_4OH$	8.36
4-nitrophenol	$O_2NC_6H_4OH$	7.15
2,4-dinitrophenol	$(O_2N)_2C_6H_3OH$	4.07
2,4,6-trinitrophenol	$(O_2N)_3C_6H_2OH$	0.42

Alcohols

Name	Formula	pK_a
methanol	CH_3OH	15.5
ethanol	C_2H_5OH	15.5

Amines

Name	Formula	pK_b
ammonia	NH_3	4.75
methylamine	CH_3NH_2	3.34
ethylamine	$CH_3CH_2NH_2$	3.35
dimethylamine	$(CH_3)_2NH$	3.27
trimethylamine	$(CH_3)_3N$	4.20
diethylamine	$(C_2H_5)_2NH$	3.16
triethylamine	$(C_2H_5)_3N$	3.25
phenylamine	$C_6H_5NH_2$	9.13

22. Acid–base indicators

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

23. Ionization constant of water at varying temperatures

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

24. Standard electrode potentials (298 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

25. Activity series

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.

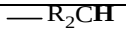
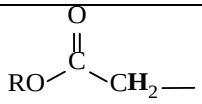
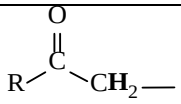
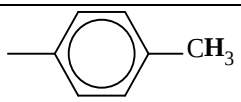
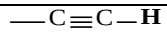
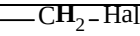
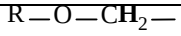
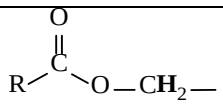
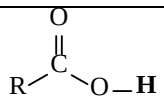
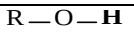
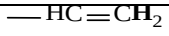
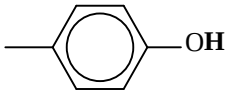
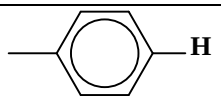
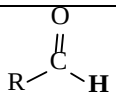
Bond	Organic molecules	Wavenumber (cm^{-1})	Intensity
C–I	iodoalkanes	490–620	strong
C–Br	bromoalkanes	500–600	strong
C–Cl	chloroalkanes	600–800	strong
C–F	fluoroalkanes	1000–1400	strong
C–O	alcohols, esters, ethers	1050–1410	strong
C=C	alkenes	1620–1680	medium-weak; multiple bands
C=O	aldehydes, ketones, carboxylic acids and esters	1700–1750	strong
C≡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. ^{1}H 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.

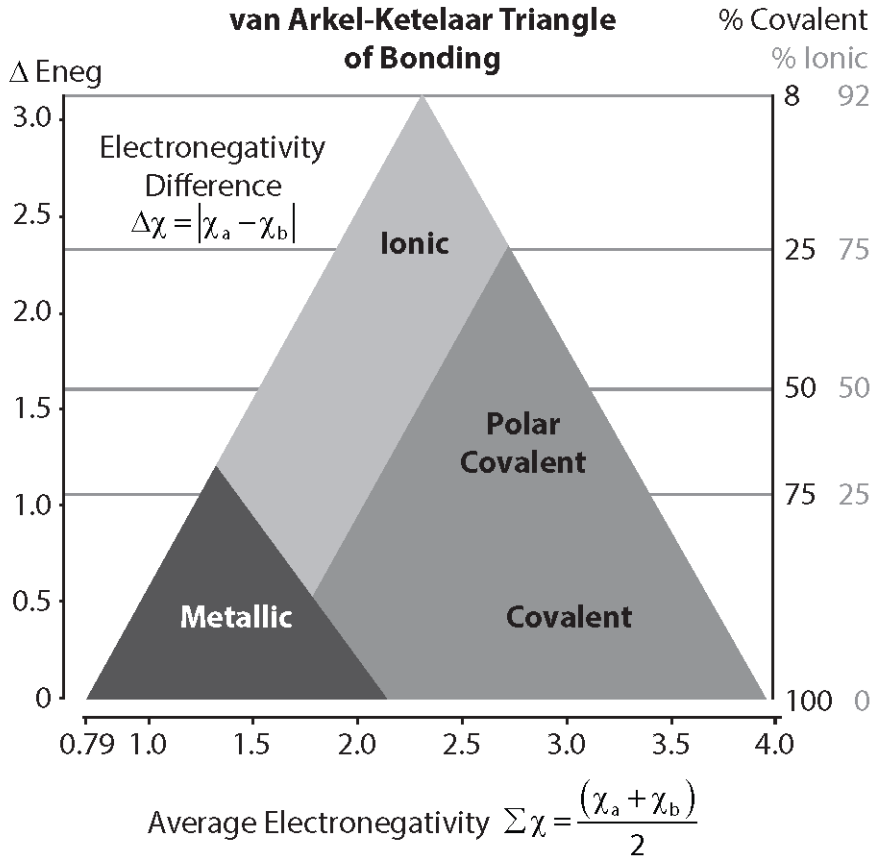
These values may vary in different solvents and conditions.

Type of proton	Chemical shift (ppm)
	0.9–1.0
	1.3–1.4
	1.5
	2.0–2.5
	2.2–2.7
	2.5–3.5
	1.8–3.1
	3.5–4.4
	3.3–3.7
	3.7–4.8
	9.0–13.0
	1.0–6.0
	4.5–6.0
	4.0–12.0
	6.9–9.0
	9.4–10.0

28. Mass spectral fragments lost

Mass lost	Fragment lost	Mass lost	Fragment lost
15	$CH_3\cdot$	29	$CH_3CH_2\cdot$, CHO·
17	OH·	31	$CH_3O\cdot$
18	H_2O	45	COOH·
28	$CH_2{=}CH_2$, C=O·		

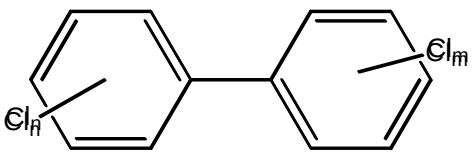
29. Triangular bonding diagram



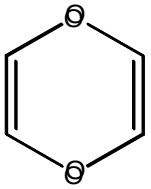
30. Resin identification codes

Resin Identification Code (RIC)	Plastic types	Resin Identification Code (RIC)	Plastic types
1 PETE	polyethylene terephthalate	5 PP	polypropylene
2 HDPE	high-density polyethylene	6 PS	polystyrene
3 PVC	polyvinyl chloride	7 OTHER	other
4 LDPE	low-density polyethylene		

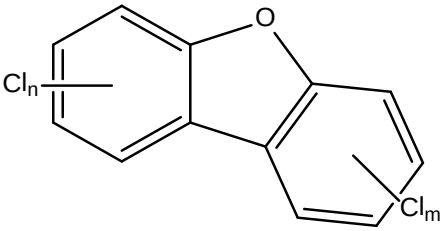
31. Representations of some materials molecules



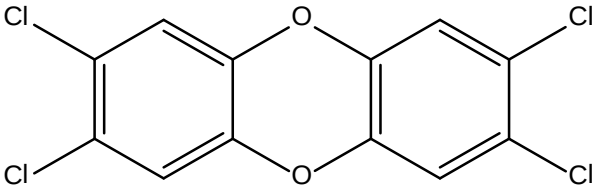
polychlorinated biphenyls



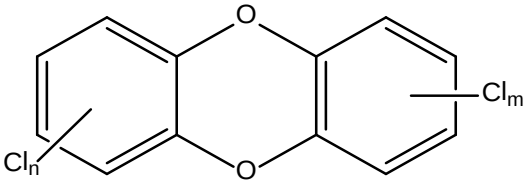
1.4-dioxin



polychlorinated dibenzofuran



2,3,7,8-tetrachlorodibenzodioxin

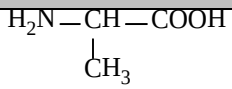
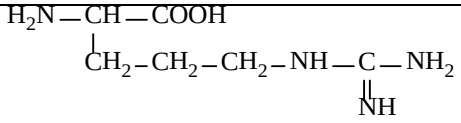
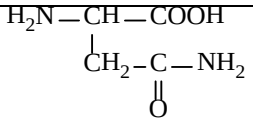
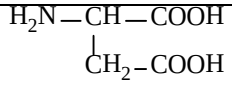
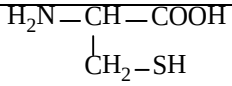
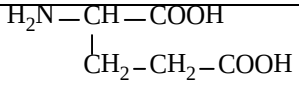
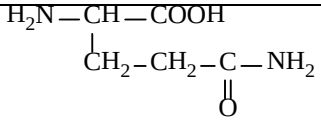
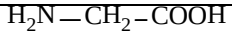
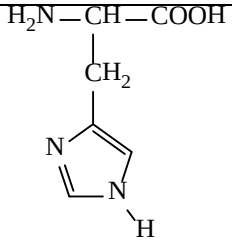
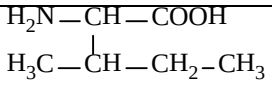
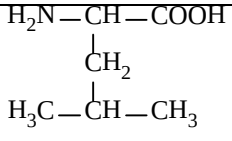
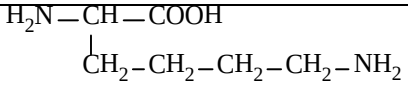
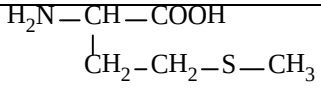


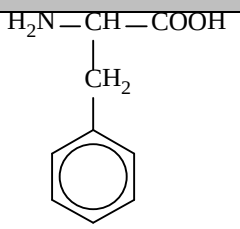
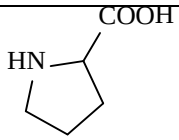
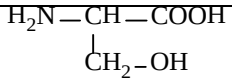
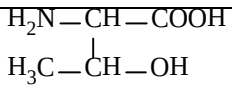
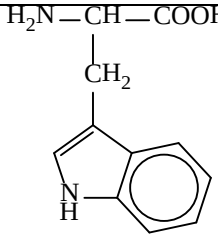
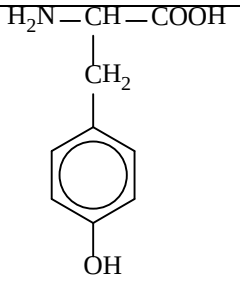
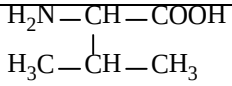
polychlorinated dibenzo-*p*-dioxin

32. Solubility product constants (at 298 K)

Compound	K_{sp}	Compound	K_{sp}
$BaCO_3$	2.58×10^{-9}	Hg_2CO_3	3.6×10^{-17}
$Ba(OH)_2 \cdot 8H_2O$	2.55×10^{-4}	Hg_2SO_4	6.5×10^{-7}
$BaSO_4$	1.08×10^{-10}	$NiCO_3$	1.42×10^{-7}
$CdCO_3$	1.0×10^{-12}	$Ni(OH)_2$	5.48×10^{-16}
$Cd(OH)_2$	7.2×10^{-15}	Ag_2CO_3	8.46×10^{-12}
$PbCO_3$	7.40×10^{-14}	Ag_2SO_4	1.20×10^{-5}
$Pb(OH)_2$	1.43×10^{-20}	$ZnCO_3$	1.46×10^{-10}
$PbSO_4$	2.53×10^{-8}	$Zn(OH)_2$	3×10^{-17}

33. 2-amino acids

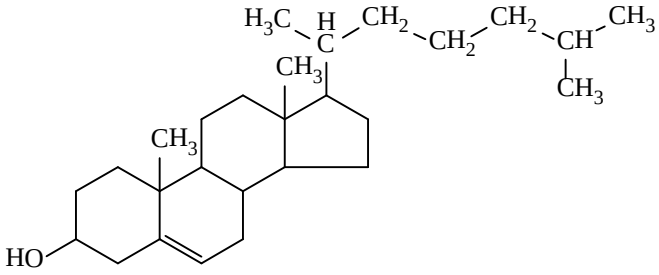
Common name	Symbol	Structural formula	pH of isoelectric point
alanine	Ala		6.0
arginine	Arg		10.8
asparagine	Asn		5.4
aspartic acid	Asp		2.8
cysteine	Cys		5.1
glutamic acid	Glu		3.2
glutamine	Gln		5.7
glycine	Gly		6.0
histidine	His		7.6
isoleucine	Ile		6.0
leucine	Leu		6.0
lysine	Lys		9.7
methionine	Met		5.7

Common name	Symbol	Structural formula	pH of isoelectric point
phenylalanine	Phe		5.5
proline	Pro		6.3
serine	Ser		5.7
threonine	Thr		5.6
tryptophan	Trp		5.9
tyrosine	Tyr		5.7
valine	Val		6.0

34. Lipids, carbohydrates and nucleotide components

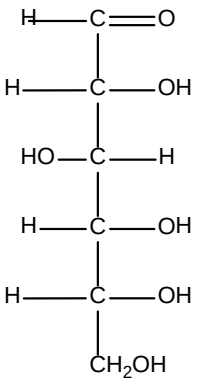
Lipids

Octanoic acid	$CH_3(CH_2)_6COOH$
Lauric acid	$CH_3(CH_2)_{10}COOH$
Palmitic acid	$CH_3(CH_2)_{14}COOH$
Stearic acid	$CH_3(CH_2)_{16}COOH$
Oleic acid	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
Linoleic acid	$CH_3(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOH$
α-Linolenic acid	$CH_3CH_2(CH=CHCH_2)_3(CH_2)_6COOH$

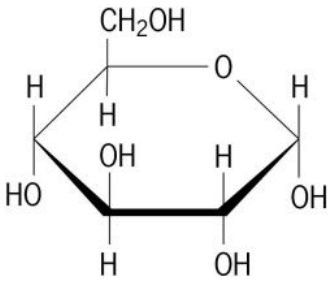


cholesterol

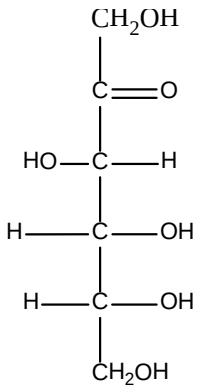
Carbohydrates



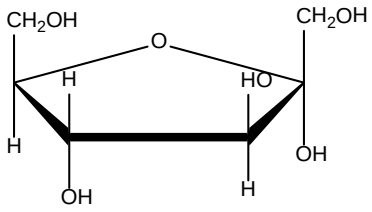
straight chain glucose



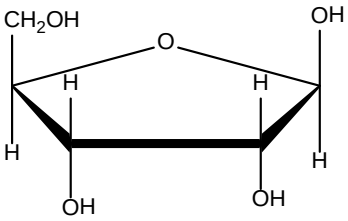
α-glucose



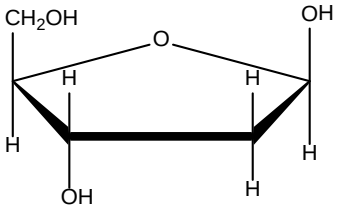
straight chain fructose



fructose

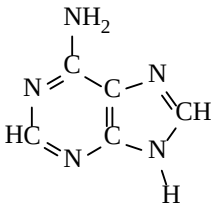


ribose

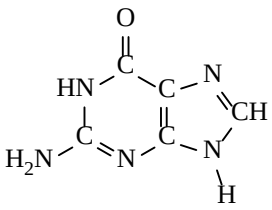


deoxyribose

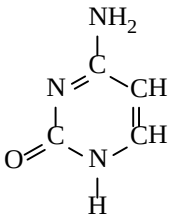
Nitrogenous bases



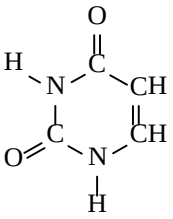
adenine



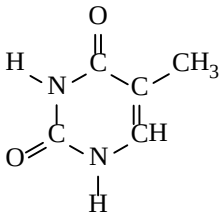
guanine



cytosine



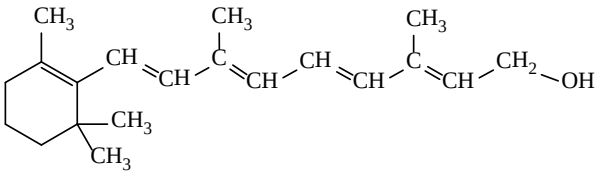
uracil



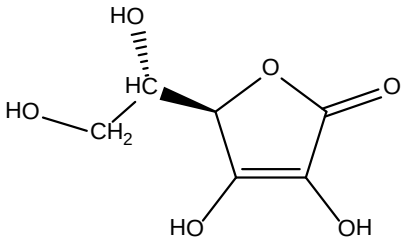
thymine

35. Vitamins and pigments

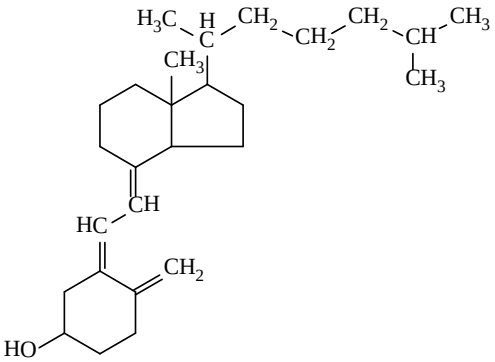
Vitamins



retinol (vitamin A)

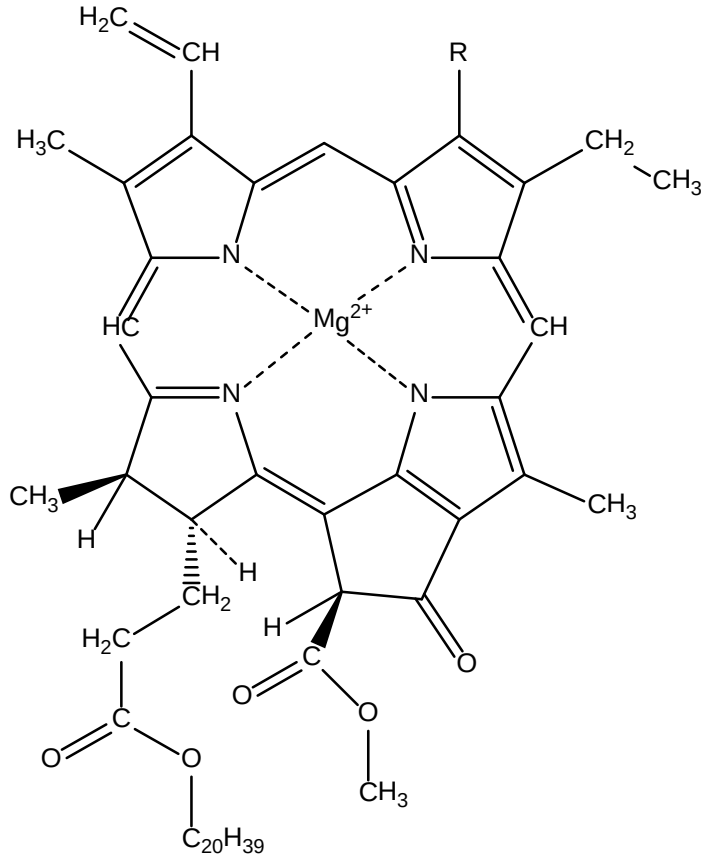


ascorbic acid (vitamin C)

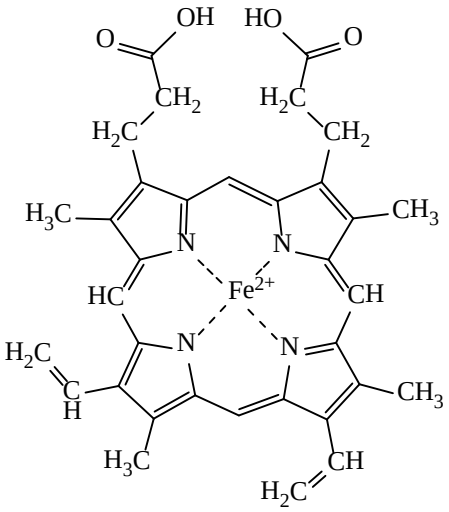


vitamin D (D3)

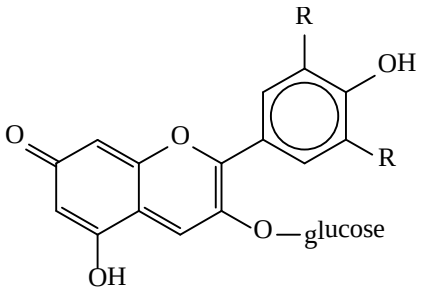
Pigments



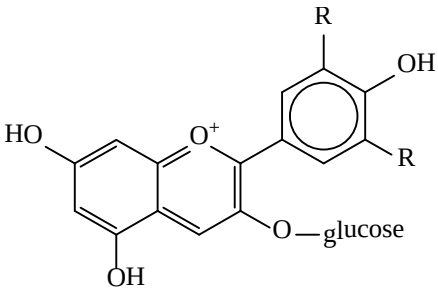
chlorophyll



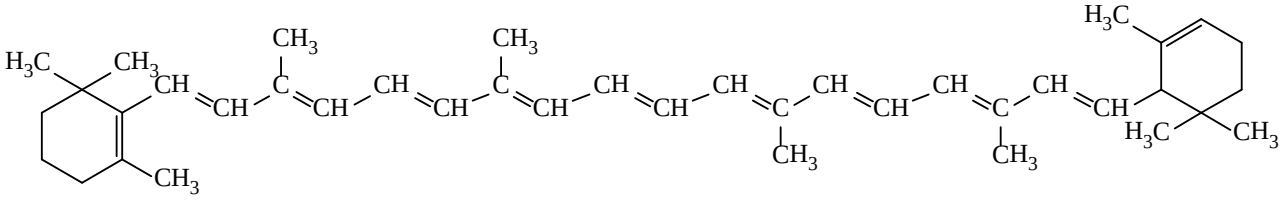
heme B



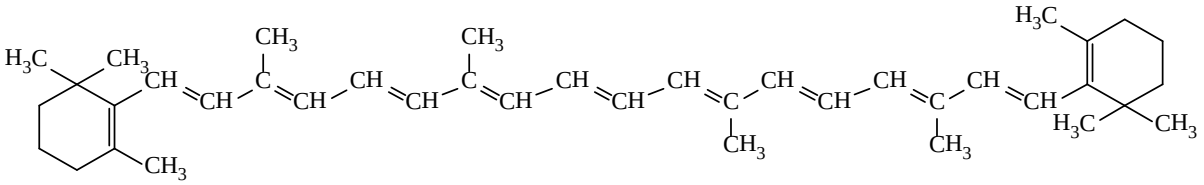
quinoidal base (blue)



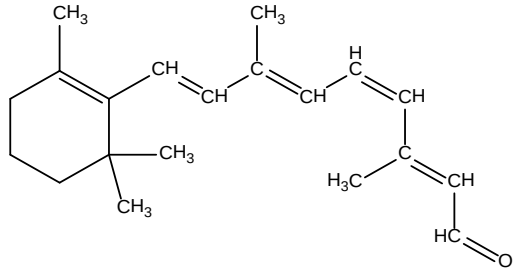
flavylium cation (red)



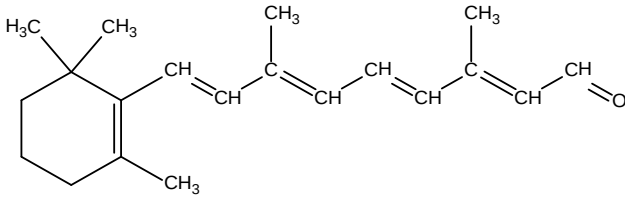
α-carotene



β-carotene

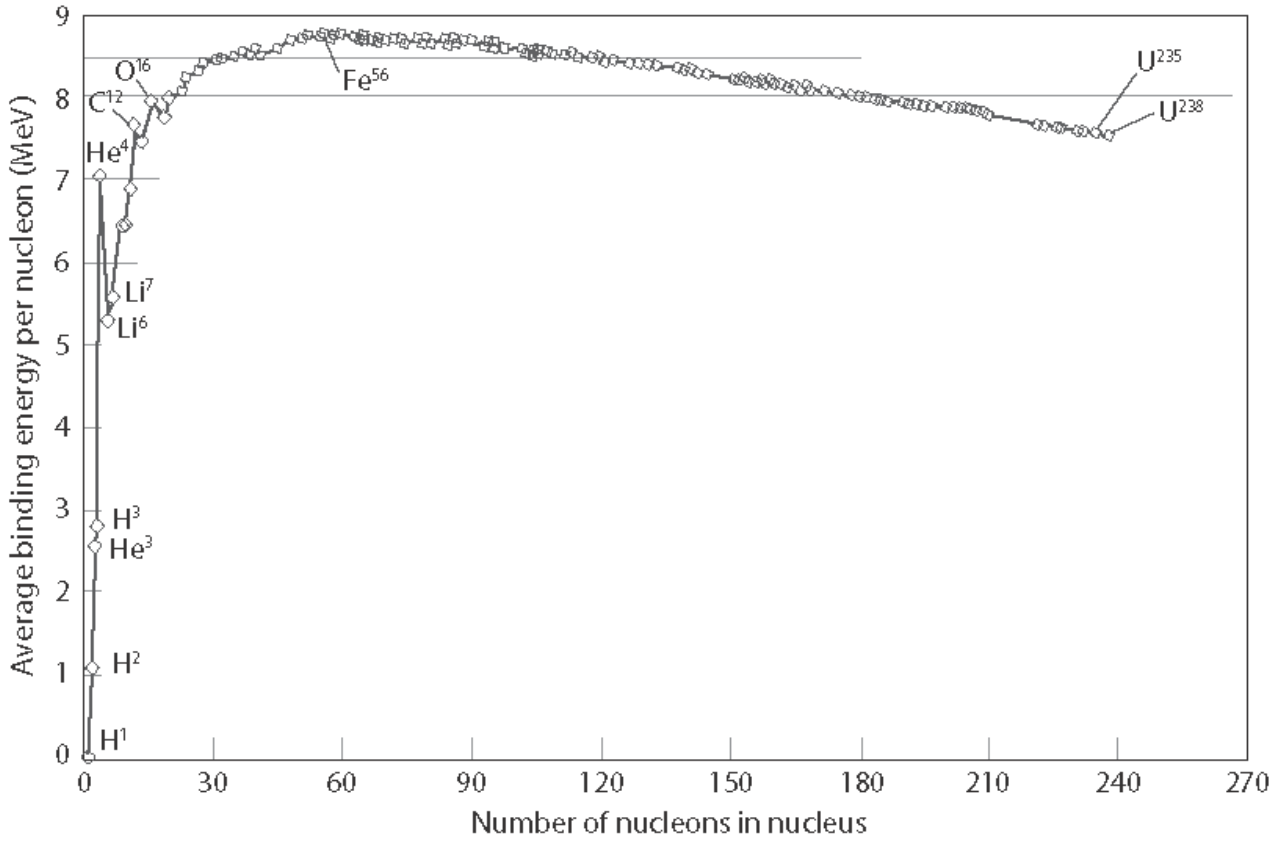


11-cis-*retinal*

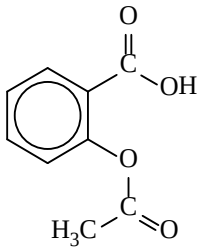


all-trans-*retinal*

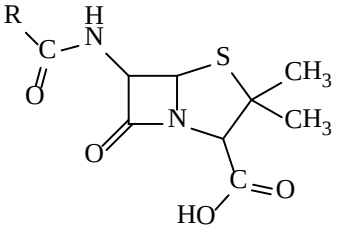
36. Binding energy curve



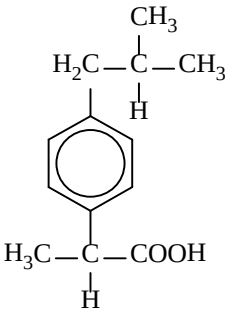
37. Representations of some medicinal molecules



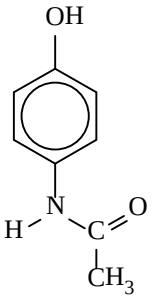
aspirin



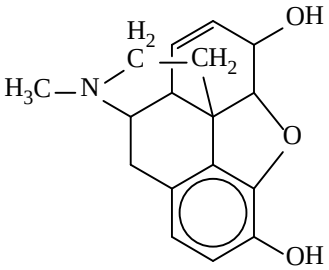
penicillin (general structure)



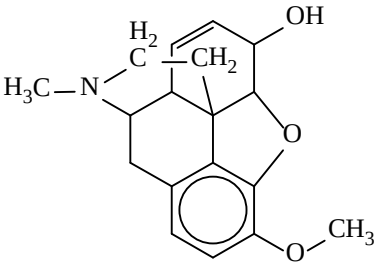
ibuprofen



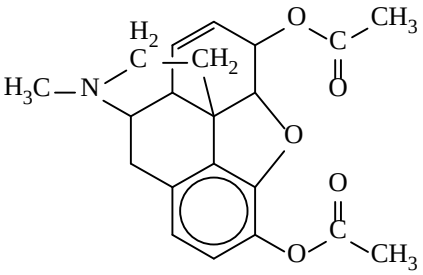
paracetamol (acetaminophen)



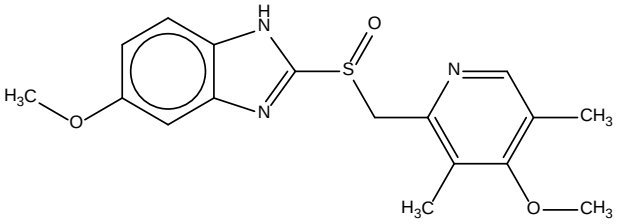
morphine



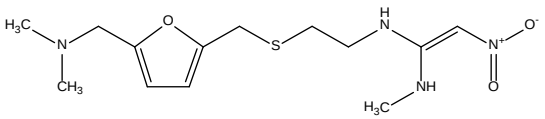
codeine



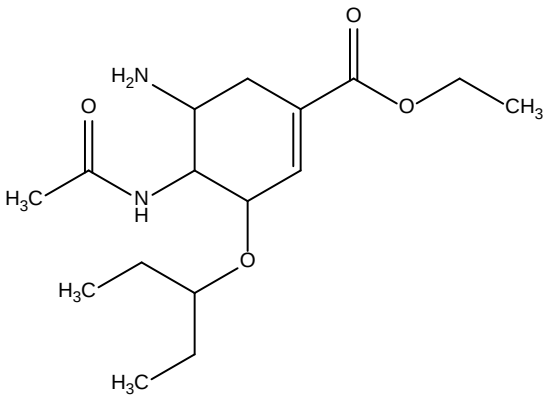
diamorphine (heroin)



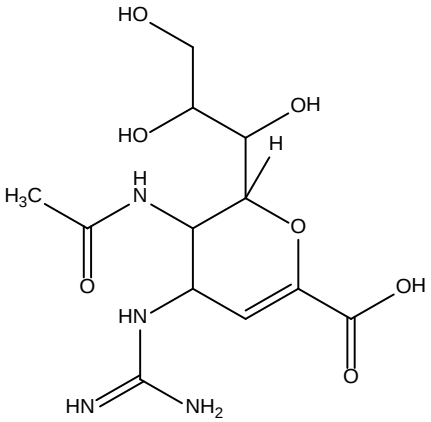
omeprazole



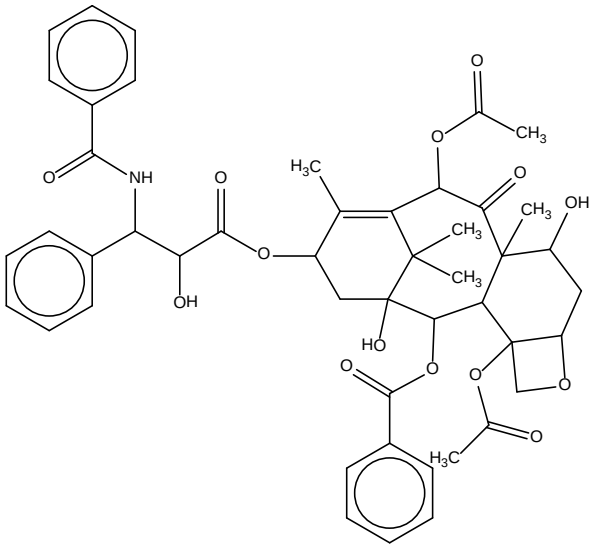
ranitidine



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.