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Notes

This booklet cannot be used for paper 1 of the examination (SLP1 and HLP1), but the periodic table given on page 3 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, SLP3, HLP2 and HLP3).

1. Some relevant equations

$$\log_{10}\frac{I_0}{I} = \varepsilon l c$$

$$k = Ae^{\frac{-E_a}{RT}}$$

$$\ln k = -\frac{E_a}{RT} = \ln A$$

$$c = f\lambda$$

$$PV = nRT$$

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

$$q = mc\Delta T$$

$$E = hf$$

2. Physical constants and unit conversions

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

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

Molar volume of an ideal gas at 273 K and 1.01×10^5 Pa = 2.24×10^{-2} m^3 mol^{-1} (= 22.4 dm^3 mol^{-1})

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

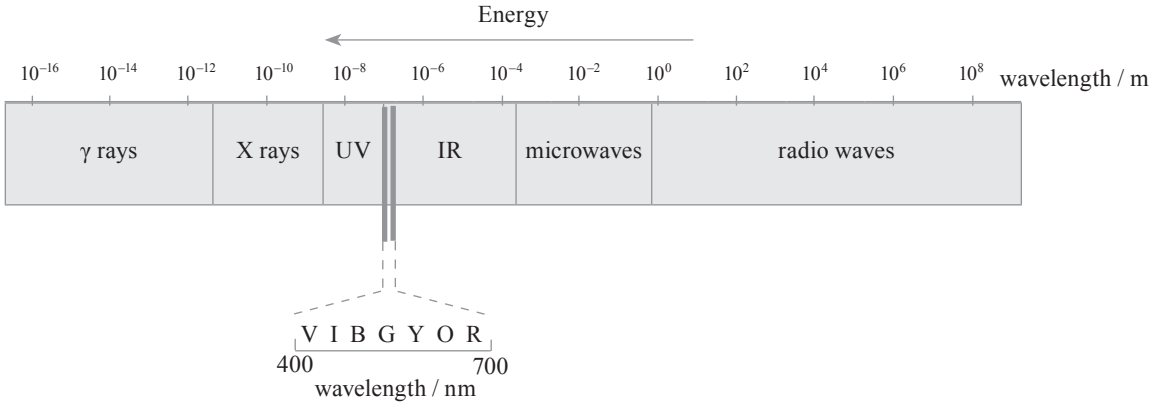
Specific heat capacity of water = 4.18 kJ kg^{-1} K^{-1} (= 4.18 J g^{-1} K^{-1})

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

1 atm = 1.01×10^5 Pa

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

3. The electromagnetic spectrum



4. 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
copper	Cu	29	rhenium	Re	75
curium	Cm	96	rhodium	Rh	45
dubnium	Db	105	rubidium	Rb	37
dysprosium	Dy	66	ruthenium	Ru	44
einsteinium	Es	99	rutherfordium	Rf	104
erbium	Er	68	samarium	Sm	62
europium	Eu	63	scandium	Sc	21
fermium	Fm	100	seaborgium	Sg	106
fluorine	F	9	selenium	Se	34
francium	Fr	87	silicon	Si	14
gadolinium	Gd	64	silver	Ag	47
gallium	Ga	31	sodium	Na	11
germanium	Ge	32	strontium	Sr	38
gold	Au	79	sulfur	S	16
hafnium	Hf	72	tantalum	Ta	73
hassium	Hs	108	technetium	Tc	43
helium	He	2	tellurium	Te	52
holmium	Ho	67	terbium	Tb	65
hydrogen	H	1	thallium	Tl	81
indium	In	49	thorium	Th	90
iodine	I	53	thulium	Tm	69
iridium	Ir	77	tin	Sn	50
iron	Fe	26	titanium	Ti	22
krypton	Kr	36	tungsten	W	74
lanthanum	La	57	uranium	U	92
lawrencium	Lr	103	vanadium	V	23
lead	Pb	82	xenon	Xe	54
lithium	Li	3	ytterbium	Yb	70
lutetium	Lu	71	yttrium	Y	39
magnesium	Mg	12	zinc	Zn	30
manganese	Mn	25	zirconium	Zr	40
meitnerium	Mt	109			

5. The periodic table

	1	2											3	4	5	6	7	0
1	1 **H** 1.01																	2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.92	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.71	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.74	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.91	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** 98.91	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** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.30
6	55 **Cs** 132.91	56 **Ba** 137.33	57 † **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.09	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.98	84 **Po** 210	85 **At** 209.99	86 **Rn** 222.02
7	87 **Fr** 223.02	88 **Ra** 226.03	89 ‡ **Ac** 227.03	104 **Rf** 260	105 **Db** 262.11	106 **Sg** 266.12	107 **Bh** 264.12	108 **Hs** 269.13	109 **Mt** 268.13									

†	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** 144.91	62 **Sm** 150.35	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** 173.04	71 **Lu** 174.97
‡	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** 239.05	94 **Pu** 239.05	95 **Am** 243.06	96 **Cm** 247.07	97 **Bk** 247.07	98 **Cf** 252.08	99 **Es** 254.09	100 **Fm** 253.09	101 **Md** 257.10	102 **No** 255.09	103 **Lr** 257

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6. Melting points and boiling points of the elements

14 **H** 20																	1 **He** 4
454 **Li** 1615	1551 **Be** 3243											2573 **B** 2823	3925 **C** 5100	63 **N** 77	55 **O** 90	53 **F** 85	25 **Ne** 27
371 **Na** 1156	922 **Mg** 1380											933 **Al** 2740	1683 **Si** 2628	317 **P** 553	392 **S** 718	172 **Cl** 238	84 **Ar** 87
336 **K** 1033	1112 **Ca** 1757	1814 **Sc** 3104	1933 **Ti** 3560	2163 **V** 3653	2130 **Cr** 2943	1517 **Mn** 2235	1808 **Fe** 3023	1768 **Co** 3143	1728 **Ni** 3003	1356 **Cu** 2840	693 **Zn** 1180	303 **Ga** 2676	1210 **Ge** 3103	1090 **As** 886	490 **Se** 958	266 **Br** 332	116 **Kr** 121
312 **Rb** 959	1042 **Sr** 1657	1795 **Y** 3611	2125 **Zr** 4650	2740 **Nb** 5015	2883 **Mo** 5833	2445 **Tc** 5150	2583 **Ru** 4173	2239 **Rh** 4000	1827 **Pd** 3243	1235 **Ag** 2485	594 **Cd** 1038	429 **In** 2353	505 **Sn** 2543	904 **Sb** 2023	723 **Te** 1263	387 **I** 457	161 **Xe** 166
302 **Cs** 942	998 **Ba** 1913	1194 **La** 3730	2500 **Hf** 4875	3269 **Ta** 5700	3683 **W** 5933	3453 **Re** 5900	2973 **Os** 5570	2683 **Ir** 4403	2045 **Pt** 4100	1337 **Au** 3353	234 **Hg** 630	577 **Tl** 1730	601 **Pb** 2013	544 **Bi** 1833	527 **Po** 1235	575 **At** 610	202 **Rn** 211
300 **Fr** 950	973 **Ra** 1413	1323 **Ac** 3473															

Melting point / K
Element
Boiling point / K

7. 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 +798 **O** 3.4	1681 –328 **F** 4.0	2081 **Ne**
496 –53 **Na** 0.9	738 **Mg** 1.3											578 –42 **Al** 1.6	789 –134 **Si** 1.9	1012 –72 **P** 2.2	1000 –200 +640 **S** 2.6	1251 –349 **Cl** 3.2	1521 **Ar**
419 –48 **K** 0.8	590 –2 **Ca** 1.0	631 –18 **Sc** 1.4	658 –8 **Ti** 1.5	650 –51 **V** 1.6	653 –64 **Cr** 1.7	717 **Mn** 1.6	759 –15 **Fe** 1.8	758 –64 **Co** 1.9	737 –112 **Ni** 1.9	746 –119 **Cu** 1.9	906 **Zn** 1.7	579 –41 **Ga** 1.8	762 –119 **Ge** 2.0	947 –79 **As** 2.2	941 –195 **Se** 2.6	1140 –325 **Br** 3.0	1351 **Kr**
403 47 **Rb** 0.8	550 –5 **Sr** 1.0	616 -30 **Y** 1.2	660 –41 **Zr** 1.3	664 –86 **Nb** 1.6	685 –72 **Mo** 2.2	702 –53 **Tc** 2.1	711 –101 **Ru** 2.2	720 –110 **Rh** 2.3	805 –54 **Pd** 2.2	731 –126 **Ag** 1.9	868 **Cd** 1.7	558 –29 **In** 1.8	709 –107 **Sn** 2.0	834 –101 **Sb** 2.1	869 –190 **Te** 2.1	1008 –295 **I** 2.7	1170 **Xe**
376 –46 **Cs** 0.8	503 –14 **Ba** 0.9	538 –45 **La** 1.1	680 **Hf** 1.3	761 –31 **Ta** 1.5	770 –79 **W** 1.7	760 –14 **Re** 1.9	840 –106 **Os** 2.2	880 –151 **Ir** 2.2	870 – 205 **Pt** 2.2	890 –223 **Au** 2.4	1007 **Hg** 1.9	589 –19 **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 –44 **Fr** 0.7	509 –10 **Ra** 0.9	499 –34 **Ac** 1.1															

First ionization energy / kJ mol^{-1} — Electron affinity / kJ mol^{-1} — 2nd EA / kJ mol^{-1}

Element

Electronegativity

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8. Atomic and ionic radii of the elements

30 **H** 154 (1–)																**He**
152 **Li** 68 (1+)	112 **Be** 30 (2+)											88 **B** 16 (3+)	77 **C** 260 (4–)	70 **N** 171 (3–)	66 **O** 146 (2–)	64 **F** 133 (1–)	**Ne**
186 **Na** 98 (1+)	160 **Mg** 65 (2+)											143 **Al** 45 (3+)	117 **Si** 42 (4+) 271 (4–)	110 **P** 212 (3–)	104 **S** 190 (2–)	99 **Cl** 181 (1–)	**Ar**
231 **K** 133 (1+)	197 **Ca** 94 (2+)	160 **Sc** 81 (3+)	146 **Ti** 90 (2+) 68 (4+)	131 **V** 88 (2+)	125 **Cr** 63 (3+)	129 **Mn** 80 (2+) 60 (4+)	126 **Fe** 76 (2+) 64 (3+)	125 **Co** 74 (2+) 63 (3+)	124 **Ni** 72 (2+)	128 **Cu** 96 (1+) 69 (2+)	133 **Zn** 74 (2+)	141 **Ga** 62 (3+)	122 **Ge** 53 (4+) 272 (4–)	121 **As** 222 (3–)	117 **Se** 202 (2–)	114 **Br** 196 (1–)	**Kr**
244 **Rb** 148 (1+)	215 **Sr** 110 (2+)	180 **Y** 93 (3+)	157 **Zr** 80 (4+)	141 **Nb** 72 (3+) 64 (5+)	136 **Mo** 68 (4+)	135 **Tc** 65 (4+) 37 (7+)	133 **Ru** 68 (3+) 62 (4+)	134 **Rh** 67 (3+) 60 (4+)	138 **Pd** 86 (2+) 62 (4+)	144 **Ag** 126 (1+)	149 **Cd** 97 (2+)	166 **In** 81 (3+)	162 **Sn** 112 (2+) 71 (4+)	141 **Sb** 245 (3–)	137 **Te** 222 (2–)	133 **I** 219 (1–)	**Xe**
262 **Cs** 167 (1+)	217 **Ba** 134 (2+)	188 **La** 115 (3+)	157 **Hf** 76 (4+)	143 **Ta** 64 (5+) 72 (6+)	137 **W** 66 (4+) 42 (6+)	137 **Re** 63 (4+) 38 (7+)	134 **Os** 63 (4+) 39 (8+)	135 **Ir** 68 (3+) 63 (4+)	138 **Pt** 80 (2+) 63 (4+)	144 **Au** 137 (1+) 85 (3+)	152 **Hg** 127 (1+) 110 (2+)	171 **Tl** 150 (1+) 93 (3+)	175 **Pb** 120 (2+) 84 (4+)	170 **Bi** 120 (3+) 76 (5+)	140 **Po** 94 (4+) 67 (6+)	140 **At** 62 (7+)	**Rn**
270 **Fr** 180 (1+)	220 **Ra** 148 (2+)	188 **Ac** 112 (3+)															

Atomic radius / 10^{-12} m

Element

Ionic radius / 10^{-12} m

9. Covalent bond lengths

Bond	Bond length / nm
H–H	0.074
C–C	0.154
C=C	0.134
C≡C	0.120
C=C (in benzene)	0.140
Si–Si	0.235
N–N	0.145
N=N	0.120
N≡N	0.110
P–P	0.221
O–O	0.148
O=O	0.121
S–S	0.205
S=S	0.189
F–F	0.142
Cl–Cl	0.199
Br–Br	0.228
I–I	0.267

Bond	Bond length / nm
C–H	0.108
Si–H	0.148
N–H	0.101
P–H	0.144
O–H	0.096
S–H	0.134
F–H	0.092
Cl–H	0.127
Br–H	0.141
I–H	0.161
C–O	0.143
C=O	0.120
C–N	0.147
C=N	0.130
C≡N	0.116
C–F	0.138
C–Cl	0.177
C–Br	0.194
C–I	0.214
Si–O	0.161

10. Bond enthalpies and average bond enthalpies at 298 K

Bond	ΔH / kJ mol^{-1}
H–H	436
C–C	347
C=C	612
C≡C	838
C=C (benzene)	505
Si–Si	226
N–N	158
N=N	410
N≡N	945
P–P	198
O–O	144
O=O	498
S–S	266
F–F	158
Cl–Cl	243
Br–Br	193
I–I	151

Bond	ΔH / kJ mol^{-1}
C–H	413
Si–H	318
N–H	391
P–H	321
O–H	464
S–H	364
F–H	568
Cl–H	432
Br–H	366
I–H	298
C–O	358
C=O	746
C–N	286
C=N	615
C≡N	887
C–F	467
C–Cl	346
C–Br	290
C–I	228
Si–O	466

11. Organic 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	–75	–51	186
ethane	C_2H_6	g	–85	–33	230
propane	C_3H_8	g	–105	–23	270
butane	C_4H_{10}	g	–127	–16	310
pentane	C_5H_{12}	l	–173	–9	261
hexane	C_6H_{14}	l	–199	–4	296
ethene	C_2H_4	g	52	68	220
propene	C_3H_6	g	20	75	267
but-1-ene	C_4H_8	g	0*	72	306
cis-but-2-ene	C_4H_8	g	–8	66	301
trans-but-2-ene	C_4H_8	g	–12	63	296
ethyne	C_2H_2	g	228	209	201
propyne	C_3H_4	g	187	194	248
buta-1,3-diene	C_4H_6	g	110	152	279
cyclohexane	C_6H_{12}	l	–156	27	204
benzene	C_6H_6	l	49	125	173
methylbenzene	$C_6H_5CH_3$	l	12	111	320
ethylbenzene	$C_6H_5CH_2CH_3$	l	–13	120	255
phenylethene	$C_6H_5CHCH_2$	l	104	203	345
chloromethane	CH_3Cl	g	–82	–57	235
dichloromethane	CH_2Cl_2	l	–124	–63	178
trichloromethane	$CHCl_3$	l	–135	–71	202
bromomethane	CH_3Br	g	–37	–26	246
iodomethane	CH_3I	l	–16	13	163
chloroethane	C_2H_5Cl	g	–137	–53	
bromoethane	C_2H_5Br	l	–91		
chlorobenzene	C_6H_5Cl	l	11	94	
methanol	CH_3OH	l	–239	–166	240
ethanol	C_2H_5OH	l	–277	–175	161
phenol	C_6H_5OH	s	–165	–48	
methanal	HCHO	g	–109	–113	219
ethanal	CH_3CHO	g	–191	–128	160
propanone	$(CH_3)_2CO$	l	–248	–155	
methanoic acid	HCOOH	l	–425	–361	129
ethanoic acid	CH_3COOH	l	–485	–390	160
benzoic acid	C_6H_5COOH	s	–385	–245	
methylamine	CH_3NH_2	g	–23	32	243

* (–0.4)

12. Enthalpies of combustion

The values of the molar enthalpy of combustion ($\Delta H_c^\ominus$) in the following table refer to a temperature of 298 K and a pressure of 1.01×10^5 Pa (1 atm).

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	–890
ethane	C_2H_6	g	–1560
propane	C_3H_8	g	–2219
butane	C_4H_{10}	g	–2877
pentane	C_5H_{12}	l	–3509
hexane	C_6H_{14}	l	–4163
octane	C_8H_{18}	l	–5470
cyclohexane	C_6H_{12}	l	–3920
ethene	C_2H_4	g	–1411
buta-1,3-diene	C_4H_6	g	–2541
ethyne	C_2H_2	g	–1301
benzene	C_6H_6	l	–3267
methylbenzene	$C_6H_5CH_3$	l	–3910
naphthalene	$C_{10}H_8$	s	–5156
chloroethane	C_2H_5Cl	g	–1413
bromoethane	C_2H_5Br	l	–1425
iodoethane	C_2H_5I	l	–1467
(chloromethyl)benzene	$C_6H_5CH_2Cl$	l	–3709
trichloromethane	$CHCl_3$	l	–474
methanol	CH_3OH	l	–726
ethanol	C_2H_5OH	l	–1367

Substance	Formula	State	$\Delta H_c^\ominus$ / kJ mol^{-1}
propan-1-ol	C_3H_7OH	l	–2021
butan-1-ol	C_4H_9OH	l	–2676
cyclohexanol	$C_6H_{11}OH$	s	–3727
phenol	C_6H_5OH	s	–3053
ethoxyethane	$(C_2H_5)_2O$	l	–2724
methanal	HCHO	g	–571
ethanal	CH_3CHO	g	–1167
benzaldehyde	C_6H_5CHO	l	–3525
propanone	$(CH_3)_2CO$	l	–1817
pentan-3-one	$(C_2H_5)_2CO$	l	–3100
phenylethanone	$CH_3COC_6H_5$	l	–4149
methanoic acid	HCOOH	l	–254
ethanoic acid	CH_3COOH	l	–874
benzoic acid	C_6H_5COOH	s	–3227
ethanedioic acid	$(COOH)_2$	s	–243
ethyl ethanoate	$CH_3COOC_2H_5$	l	–2238
ethanamide	CH_3CONH_2	s	–1185
methylamine	CH_3NH_2	g	–1085
ethylamine	$C_2H_5NH_2$	g	–1740
phenylamine	$C_6H_5NH_2$	l	–3393
nitrobenzene	$C_6H_5NO_2$	l	–3088
urea	$CO(NH_2)_2$	s	–632
glucose	$C_6H_{12}O_6$	s	–2803
sucrose	$C_{12}H_{22}O_{11}$	s	–5640

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13. Lattice enthalpies at 298 K (experimental and theoretical values)

The lattice enthalpy values $(\Delta H^{\ominus}_{\text{lattice}})$ given relate to the endothermic process for a solid crystal breaking into gaseous ions.

For example, for an alkali metal halide:

$MX(s) \rightarrow M^{+}(g) + X^{-}(g)$

Experimental values

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

Alkali metal halides	$\Delta H^{\ominus}_{\text{lattice}}$ / 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	$\Delta H^{\ominus}_{\text{lattice}}$ / kJ mol^{-1}	Other substances	$\Delta H^{\ominus}_{\text{lattice}}$ / 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		

Theoretical values

These two tables contain lattice enthalpies calculated from electrostatic principles on the basis of a purely ionic model for the crystal.

Alkali metal halides	$\Delta H^{\ominus}_{lattice}$ / kJ mol^{-1}			
	F	Cl	Br	I
Li	1030	834	788	730
Na	910	769	732	682
K	808	701	671	632
Rb	774	680	651	617
Cs	744	657	632	600

Other substances	$\Delta H^{\ominus}_{lattice}$ / kJ mol^{-1}	Other substances	$\Delta H^{\ominus}_{lattice}$ / kJ mol^{-1}
CaF_2	2640	AgF	953
MgO	3795	AgCl	910
CaO	3414	AgBr	897
SrO	3217	AgI	881
BaO	3029		

14. Standard electrode potentials

Oxidized species		Reduced species	$E^\ominus$ / 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
$Mn^{2+}(aq) + 2e^-$	⇌	$Mn(s)$	–1.19
$H_2O(l) + e^-$	⇌	$½H_2(g) + OH^-(aq)$	–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
$H^+(aq) + e^-$	⇌	$½H_2(g)$	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
$½O_2(g) + H_2O(l) + 2e^-$	⇌	$2OH^-(aq)$	+0.40
$Cu^+(aq) + e^-$	⇌	$Cu(s)$	+0.52
$½I_2(s) + e^-$	⇌	$I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^-$	⇌	$Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^-$	⇌	$Ag(s)$	+0.80
$½Br_2(l) + e^-$	⇌	$Br^-(aq)$	+1.07
$½O_2(g) + 2H^+(aq) + 2e^-$	⇌	$H_2O(l)$	+1.23
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	⇌	$2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$½Cl_2(g) + e^-$	⇌	$Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^-$	⇌	$Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$½F_2(g) + e^-$	⇌	$F^-(aq)$	+2.87

15. 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

16. Acid–base indicators

Indicator	pK_a	pH range	Colour change	
			Acid	Alkali
methyl orange	3.46	3.2–4.4	red	yellow
bromophenol blue	4.10	3.0–4.6	yellow	blue
bromocresol green	4.90	3.8–5.4	yellow	blue
methyl red	5.00	4.8–6.0	red	yellow
bromothymol blue	7.30	6.0–7.6	yellow	blue
phenol red	8.00	6.6–8.0	yellow	red
phenolphthalein	9.50	8.2–10.0	colourless	pink

17. Infrared data

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

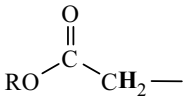
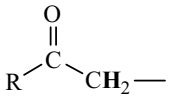
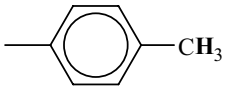
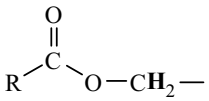
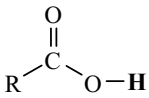
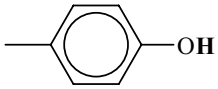
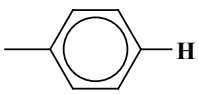
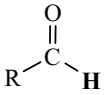
Bond	Organic molecules	Wavenumber / cm^{-1}
C–I	iodoalkanes	490–620
C–Br	bromoalkanes	500–600
C–Cl	chloroalkanes	600–800
C–F	fluoroalkanes	1000–1400
C–O	alcohols, esters, ethers	1050–1410
C=C	alkenes	1610–1680
C=O	aldehydes, ketones, carboxylic acids and esters	1700–1750
C≡C	alkynes	2100–2260
O–H	hydrogen bonding in carboxylic acids	2500–3300
C–H	alkanes, alkenes, arenes	2850–3100
O–H	hydrogen bonding in alcohols and phenols	3200–3600
N–H	primary amines	3300–3500

18. ^{1}H NMR data

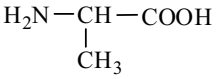
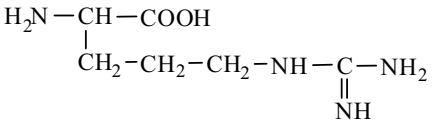
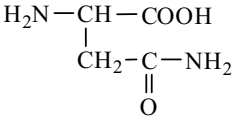
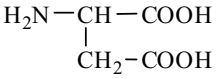
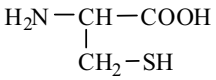
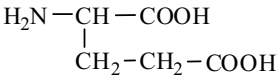
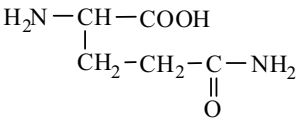
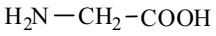
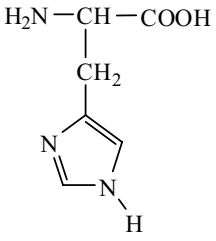
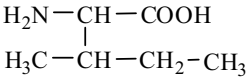
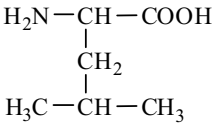
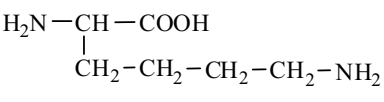
Typical proton chemical shift values (δ) relative to tetramethylsilane (TMS) = 0.

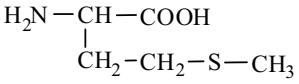
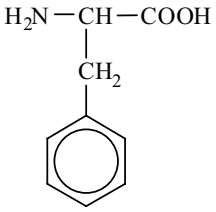
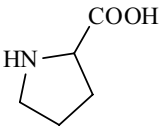
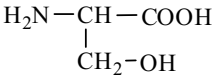
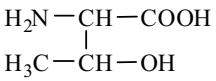
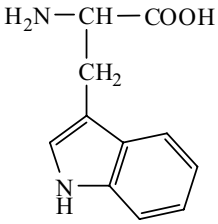
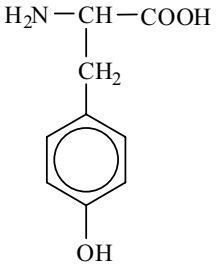
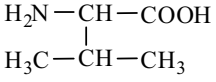
R represents an alkyl group, and Hal represents F, Cl, Br, or I.

These values may vary in different solvents and conditions.

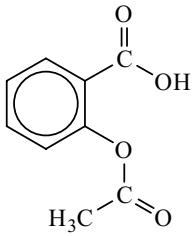
Type of proton	Chemical shift / ppm
—C**H**$_3$	0.9–1.0
—C**H**$_2$-R	1.3–1.4
—C**H**R$_2$	1.4–1.6
	2.0–2.5
	2.2–2.7
	2.5–3.5
—C≡C—**H**	1.8–3.1
—C**H**$_2$-Hal	3.5–4.4
R—O—C**H**$_2$—	3.3–3.7
	3.8–4.1
	9.0–13.0
R—O—**H**	4.0–12.0
—HC=C**H**$_2$	4.5–6.0
	4.0–12.0
	6.9–9.0
	9.4–10.0

19. 2-Amino acids

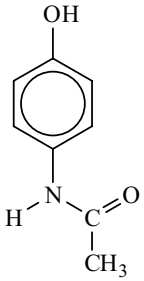
Common name	Symbol	Structural formula	pH of isoelectric point
alanine	Ala		6.0
arginine	Arg		10.8
asparagine	Asn		5.4
aspartic acid	Asp		2.8
cysteine	Cys		5.1
glutamic acid	Glu		3.2
glutamine	Gln		5.7
glycine	Gly		6.0
histidine	His		7.6
isoleucine	Ile		6.0
leucine	Leu		6.0
lysine	Lys		9.7

Common name	Symbol	Structural formula	pH of isoelectric point
methionine	Met		5.7
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

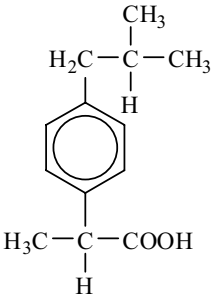
20. Structural formulas of some medicines and drugs



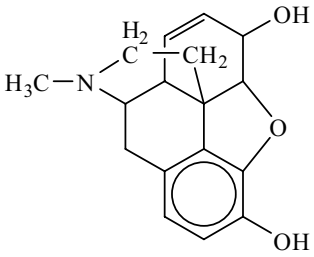
aspirin



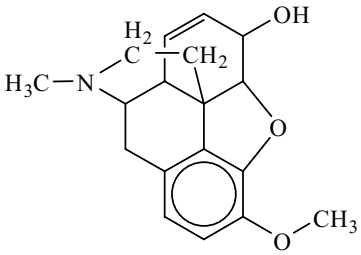
paracetamol (acetaminophen)



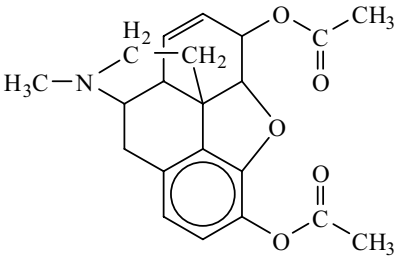
ibuprofen



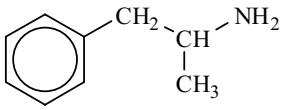
morphine



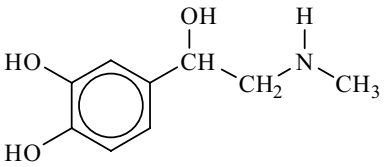
codeine



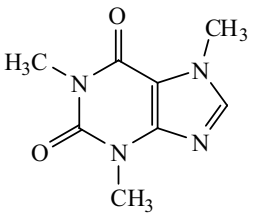
diamorphine (heroin)



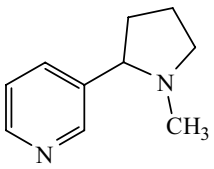
amphetamine



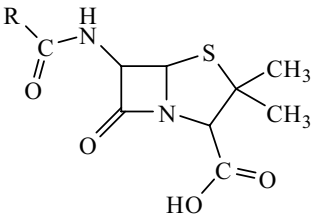
epinephrine (adrenaline)



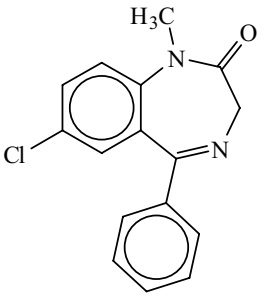
caffeine



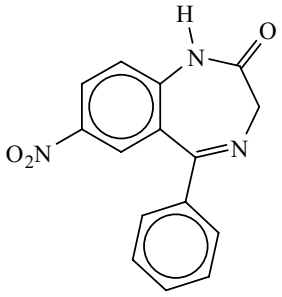
nicotine



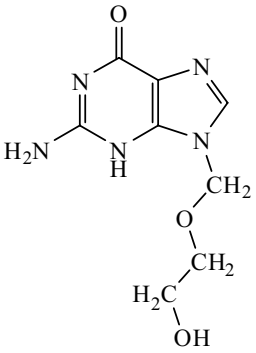
penicillin
(general structure)



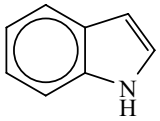
diazepam (Valium®)



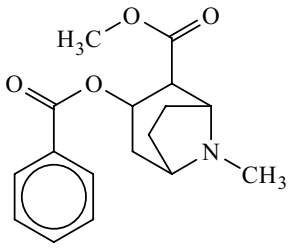
nitrazepam (Mogadon®)



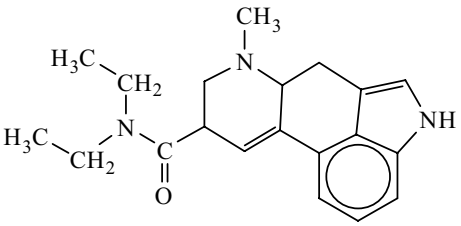
acyclovir



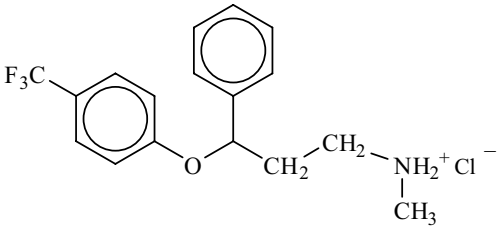
indole



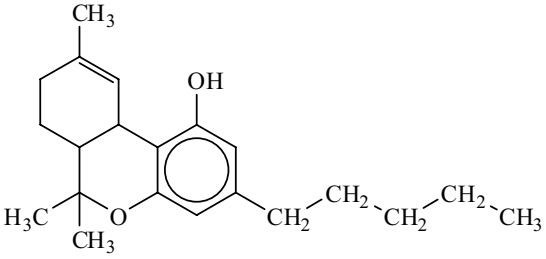
cocaine



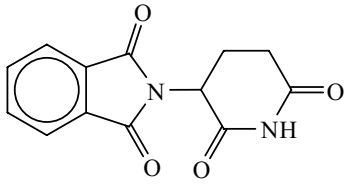
lysergic acid diethylamide (LSD)



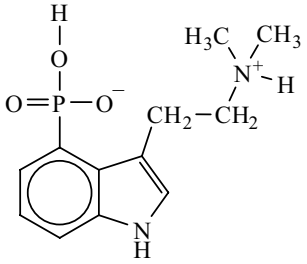
fluoxetine hydrochloride (Prozac®)



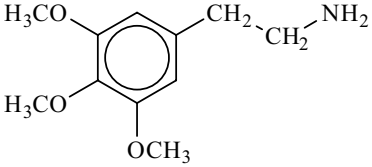
tetrahydrocannabinol (THC)



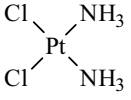
thalidomide



psilocybin

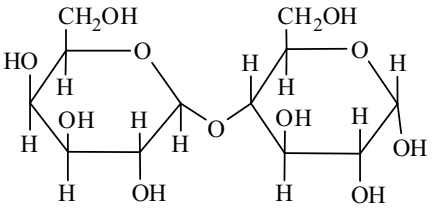


mescaline

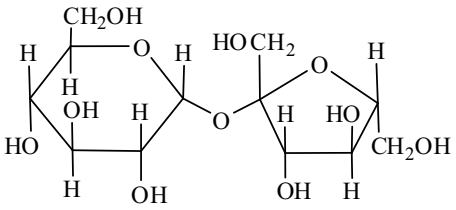


cisplatin

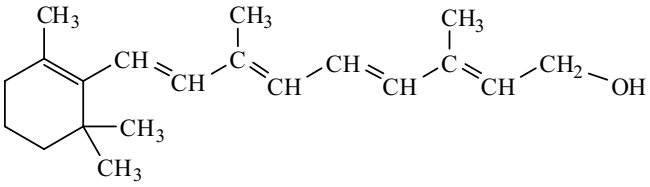
21. Structural formulas of some biological molecules



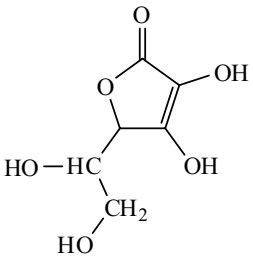
lactose



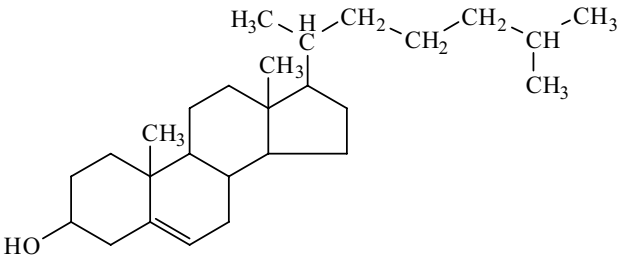
sucrose



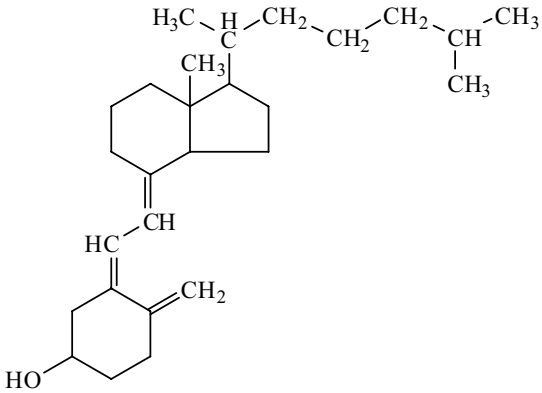
retinol (vitamin A)



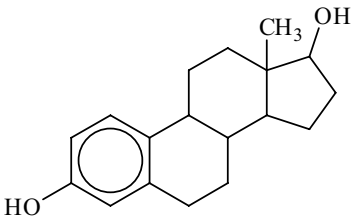
ascorbic acid (vitamin C)



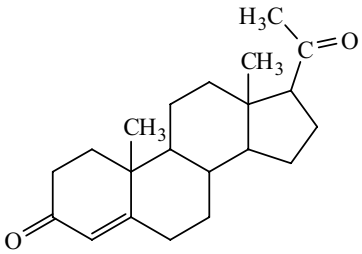
cholesterol



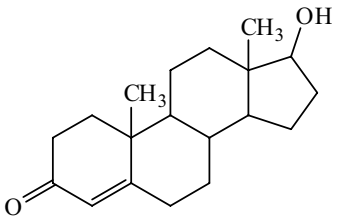
vitamin D



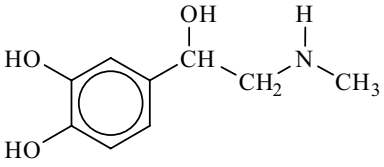
estradiol



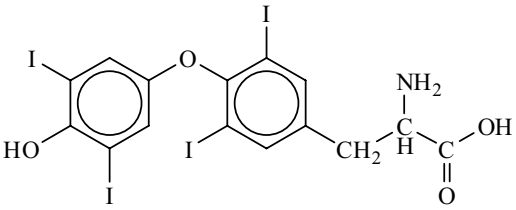
progesterone



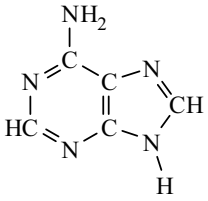
testosterone



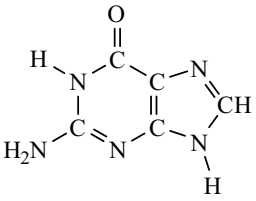
epinephrine (adrenaline)



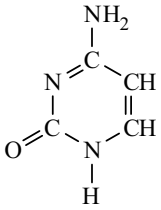
thyroxine



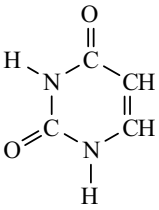
adenine



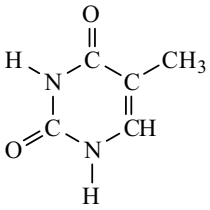
guanine



cytosine



uracil

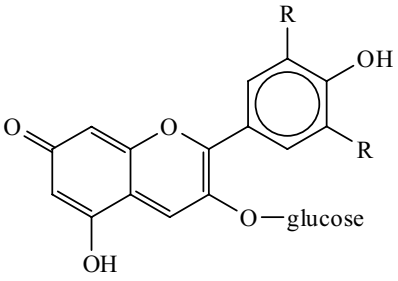


thymine

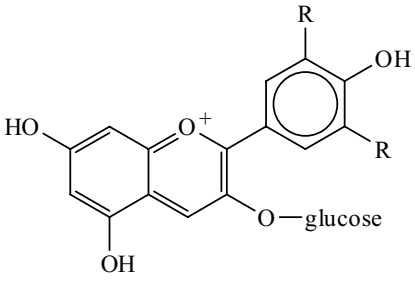
22. Structural formulas of some food chemistry molecules

Natural pigments

Anthocyanins

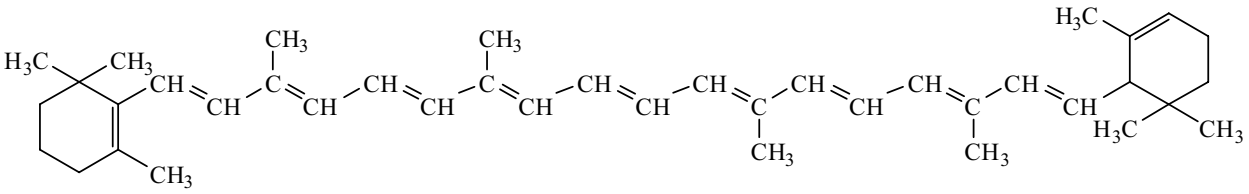


quinoidal base (blue)

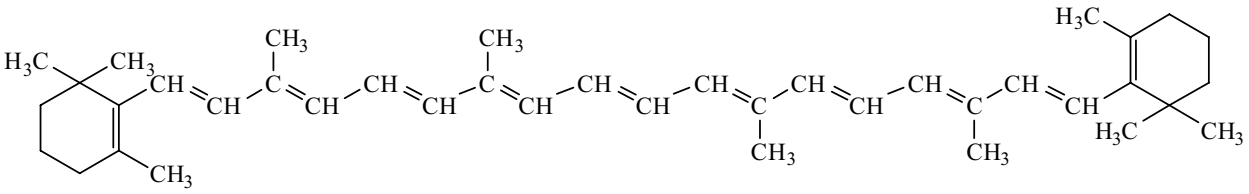


flavylium cation (red)

Carotenes

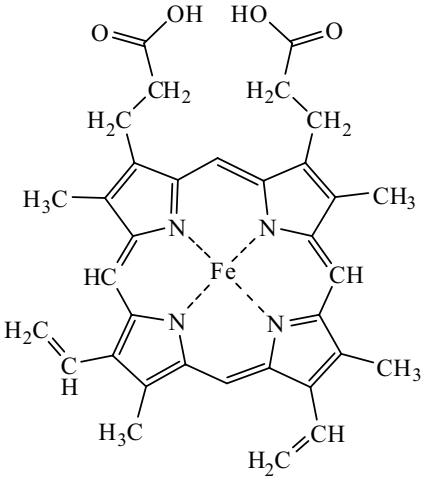


α-carotene

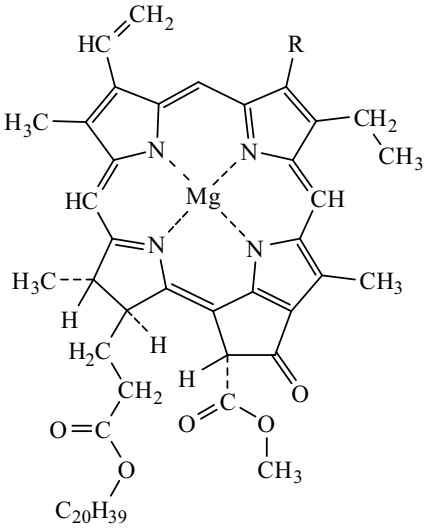


β-carotene

Porphyrins



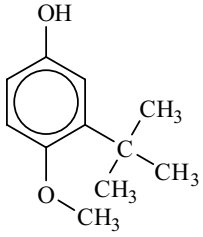
heme B



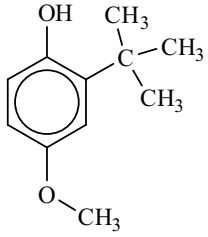
R=CH_3 (Chlorophyll a)
R=CHO (Chlorophyll b)

chlorophyll

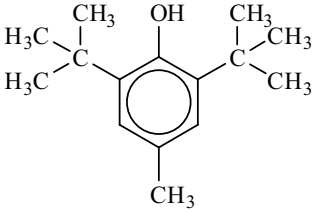
Preservatives



2-*tert*-butyl-4-hydroxyanisole (2-BHA)



3-*tert*-butyl-4-hydroxyanisole (3-BHA)



3,5-di-*tert*-butyl-4-hydroxytoluene (BHT)

Fatty acids

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

23. References

The data in tables 4–16 can be found in the following three sources.

Lide, DR. 2008. *CRC Handbook of Chemistry and Physics*. Boca Raton, USA. CRC Press. Copyright 2008 by *CRC Handbook of Chemistry and Physics*. David R Lide. Reproduced by permission from Taylor and Francis Group, LLC, a division of Informa plc.

NVON. 2007. *Binas*. English Edition. Groningen, The Netherlands. Wolters–Noordhoff.

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For tables 17 and 18, in addition to the sources above, the data were informed by the following.

Aylward, G and Findlay, T. 2002. *SI Chemical Data*. 5th Edition. Queensland, Australia. John Wiley & Sons.

Clugston, M and Flemming, R. 2000. *Advanced Chemistry*. Oxford, UK. Oxford University Press.

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