Salters Advanced Chemistry

Data Sheets

Contents

Introduction

These Data Sheets contain some basic information that you will use throughout the Salters Advanced Chemistry course. For more detailed information you will need to consult a data book such as *The Elements* by John Emsley (Oxford, third edition, 1998) or *S I Chemical Data* by Gordon Aylward and Tristan Findlay (Wiley, fourth edition, 1999).

The information in these Data Sheets is taken from these books, from where primary references can be found, and from *Inorganic Energetics* by W E Dasent (Cambridge, second edition, 1982) and the Salters Advanced Chemistry course.

Table 1: Fundamental constants

Quantity	Symbol	Value	Unit
speed of light in a vacuum	c	3.00×10^{8}	$m\,s^{-1}$
Planck constant	h	6.63×10^{-34}	$J\,Hz^{-1}$
Avogadro constant	L	6.02×10^{23}	mol^{-1}
gas constant	R	8.31	$J\,K^{-1}\,mol^{-1}$

Other useful constants

	Symbol	Value	Unit
molar volume of an ideal gas at s.t.p. (273 K and 1 atmosphere)	V_m	22.4	$dm^3\,mol^{-1}$
specific heating capacity of water	c_p	4.17	$J\,g^{-1}\,K^{-1}$

Table 2: Standard temperature

For thermodynamic measurements, such as enthalpy and entropy changes and standard electrode potentials, the standard temperature used is 298 K (25 °C) unless stated.

For measurements of gas volumes, the standard temperature used is 273 K (0 °C). Standard temperature and pressure (s.t.p.) is 273 K and 101.325 kPa.

Table 3: Units of pressure

Pressure is measured in pascals (Pa): $1\,Pa = 1\,N\,m^{-2}$.

An atmosphere (atm) is the pressure needed to push a column of mercury in a barometer to a height of 760 mm (standard atmospheric pressure): 1 atm = 101.325 kPa.

Table 4: SI prefixes

The following prefixes are used to indicate decimal fractions or multiples of SI units:

10^{-12}	pico	p	10^{3}	kilo	k
10^{-9}	nano	n	10^{6}	mega	M
10^{-6}	micro	μ	10^{9}	giga	G
10^{-3}	milli	m	10^{12}	tera	T
10^{-2}	centi	c			
10^{-1}	deci	d			

Table 5: Definition of billion

Throughout the course a *billion* refers to a thousand million: 1 billion = 1×10^{9}.

Table 6: Use of parts per million (ppm)

Parts per million are frequently used to express low concentrations. It is important to know exactly what the measurements refer to.

For mixtures of gases, parts per million *by volume* are usually used: ppm (by volume). For example, the concentration of carbon dioxide in the atmosphere at the time of publication is 367 ppm (by volume). This means that in 1 million molecules of air there are 367 molecules of CO_2; 367 ppm (by volume) is the same as 0.0367% (by volume).

For solids and liquids, parts per million *by mass* are usually used. For example, the concentration of pesticide residues in a plant may be measured in ppm (by mass) of plant tissue. A pesticide concentration of 1 ppm means that 1 g of plant tissue contains 1×10^{-6} g (1 μg) of pesticide.

Table 7: The Periodic Table

Group 1 2 3 4 5 6 7 0

Period 1

																	4.0 $_{2}$He helium

s block — d block — p block

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2	6.9 $_{3}$Li lithium	9.0 $_{4}$Be beryllium											10.8 $_{5}$B boron	12.0 $_{6}$C carbon	14.0 $_{7}$N nitrogen	16.0 $_{8}$O oxygen	19.0 $_{9}$F fluorine	20.2 $_{10}$Ne neon
3	23.0 $_{11}$Na sodium	24.3 $_{12}$Mg magnesium											27.0 $_{13}$Al aluminium	28.1 $_{14}$Si silicon	31.0 $_{15}$P phosphorus	32.1 $_{16}$S sulphur	35.5 $_{17}$Cl chlorine	39.9 $_{18}$Ar argon
4	39.1 $_{19}$K potassium	40.1 $_{20}$Ca calcium	45.0 $_{21}$Sc scandium	47.9 $_{22}$Ti titanium	50.9 $_{23}$V vanadium	52.0 $_{24}$Cr chromium	54.9 $_{25}$Mn manganese	55.9 $_{26}$Fe iron	58.9 $_{27}$Co cobalt	58.7 $_{28}$Ni nickel	63.5 $_{29}$Cu copper	65.4 $_{30}$Zn zinc	69.7 $_{31}$Ga gallium	72.6 $_{32}$Ge germanium	74.9 $_{33}$As arsenic	79.0 $_{34}$Se selenium	79.9 $_{35}$Br bromine	83.8 $_{36}$Kr krypton
5	85.5 $_{37}$Rb rubidium	87.6 $_{38}$Sr strontium	88.9 $_{39}$Y yttrium	91.2 $_{40}$Zr zirconium	92.9 $_{41}$Nb niobium	95.9 $_{42}$Mo molybdenum	(99) $_{43}$Tc technetium	101.1 $_{44}$Ru ruthenium	102.9 $_{45}$Rh rhodium	106.4 $_{46}$Pd palladium	107.9 $_{47}$Ag silver	112.4 $_{48}$Cd cadmium	114.8 $_{49}$In indium	118.7 $_{50}$Sn tin	121.8 $_{51}$Sb antimony	127.6 $_{52}$Te tellurium	126.9 $_{53}$I iodine	131.3 $_{54}$Xe xenon
6	132.9 $_{55}$Cs caesium	137.3 $_{56}$Ba barium	138.9 $_{57}$La lanthanum	178.5 $_{72}$Hf hafnium	181.0 $_{73}$Ta tantalum	183.9 $_{74}$W tungsten	186.2 $_{75}$Re rhenium	190.2 $_{76}$Os osmium	192.2 $_{77}$Ir iridium	195.1 $_{78}$Pt platinum	197.0 $_{79}$Au gold	200.6 $_{80}$Hg mercury	204.4 $_{81}$Tl thallium	207.2 $_{82}$Pb lead	209.0 $_{83}$Bi bismuth	(210) $_{84}$Po polonium	(210) $_{85}$At astatine	(222) $_{86}$Rn radon
7	(223) $_{87}$Fr francium	(226) $_{88}$Ra radium	(227) $_{89}$Ac actinium	(261) $_{104}$Rf rutherfordium	(262) $_{105}$Db dubnium	(266) $_{106}$Sg seaborgium	(264) $_{107}$Bh bohrium	(269) $_{108}$Hs hassium	(268) $_{109}$Mt meitnerium	(269) $_{110}$Uun ununnilium	(272) $_{111}$Uuu unununium	(277) $_{112}$Uub ununbium		(285) $_{114}$Uuq ununquadium		(289) $_{116}$Uuh ununhexium		(293) $_{118}$Uuo ununoctium

f block

Lanthanide elements	140.1 $_{58}$Ce cerium	140.9 $_{59}$Pr praseo-dymium	144.2 $_{60}$Nd neodymium	(147) $_{61}$Pm promethium	150.4 $_{62}$Sm samarium	152.0 $_{63}$Eu europium	157.3 $_{64}$Gd gadolinium	158.9 $_{65}$Tb terbium	162.5 $_{66}$Dy dysprosium	164.9 $_{67}$Ho holmium	167.3 $_{68}$Er erbium	168.9 $_{69}$Tm thulium	173.0 $_{70}$Yb ytterbium	175.0 $_{71}$Lu lutetium
Actinide elements	232.0 $_{90}$Th thorium	(231) $_{91}$Pa protactinium	238.1 $_{92}$U uranium	(237) $_{93}$Np neptunium	(242) $_{94}$Pu plutonium	(243) $_{95}$Am americium	(247) $_{96}$Cm curium	(245) $_{97}$Bk berkelium	(251) $_{98}$Cf californium	(254) $_{99}$Es einsteinium	(253) $_{100}$Fm fermium	(256) $_{101}$Md mendelevium	(254) $_{102}$No nobelium	(257) $_{103}$Lr lawrencium

f block

KEY

6.9 — relative atomic mass
$_{3}$Li — symbol (atomic number)
lithium

An entry in brackets indicates the mass number of the longest-lived isotope of an element with no stable isotopes

Table 8: Physical and thermochemical data for the first 36 elements

Z	Atomic number
St	Normal physical state at 298 K and 1 atm pressure (s, solid; l, liquid; g, gas)
A	Molar mass of the element (the mole applies to single atoms)
ρ	Density at 298 K and 1 atm pressure (or density of liquid at T_b for gases)
T_m	Melting point } at 1 atm except where stated otherwise
T_b	Boiling point } at 1 atm except where stated otherwise
$\Delta H_{fus}^{\ominus}$	Standard molar enthalpy change of fusion at T_m and 1 atm
$\Delta H_{vap}^{\ominus}$	Standard molar enthalpy change of vaporisation at T_b and 1 atm
$S^{\ominus}$	Standard molar entropy at 298 K and 1 atm

^{sub} sublimes; ^{ign} ignites; * variable; † uncertain

Z	Element		St	A/ g mol^{-1}	ρ/g cm^{-3}	T_m/K	T_b/K	$\Delta H_{fus}^{\ominus}$/ kJ mol^{-1}	$\Delta H_{vap}^{\ominus}$/ kJ mol^{-1}	$S^{\ominus}$/ J K^{-1} mol^{-1}
1	hydrogen	H	g	1.0	0.07^{20K}	14	20	0.12	0.46	130.7
2	helium	He	g	4.0	0.15^{4K}	1^{26atm}	4	0.02	0.08	126.2
3	lithium	Li	s	6.9	0.53	454	1620	4.60	134.7	29.1
4	beryllium	Be	s	9.0	1.85	1551±5	3243	9.80	308.8	9.5
5	boron	B	s	10.8	2.34	2573	3931	22.2	538.9	5.9
6	carbon (graphite)	C	s	12.0	2.26	$3925–70^{sub}$	5100^{sub}	105.0	710.9^{sub}	5.7
6	carbon (diamond)	C	s	12.0	3.51	>3820	–	–	–	2.4
7	nitrogen	N	g	14.0	1.03^{21K}	63	77	0.72	5.58	191.6
8	oxygen	O	g	16.0	2.00^{55K}	55	90	0.44	6.82	205.1
9	fluorine	F	g	19.0	1.52^{85K}	54	85	5.10	6.55	202.8
10	neon	Ne	g	20.2	1.44^{29K}	24	27	0.32	1.74	146.3
11	sodium	Na	s	23.0	0.97	371	1156	2.64	89.0	51.2
12	magnesium	Mg	s	24.3	1.74	922	1363	9.04	128.7	32.7
13	aluminium	Al	s	27.0	2.70	934	2740	10.7	293.7	28.3
14	silicon	Si	s	28.1	2.33	1683	2628	39.6	383.3	18.8
15	phosphorus (red)	P	s	31.0	2.20	683^{43atm}	683	–	–	22.8
15	phosphorus (white)	P	s	31.0	1.82	317	553	2.51	51.9	41.1
16	sulphur (rhombic)	S	s	32.1	2.07	386	718	–	–	31.8
16	sulphur (monoclinic)	S	s	32.1	1.96	392	718	1.23	9.62	–
17	chlorine	Cl	g	35.5	2.03^{113K}	172	239	6.41	20.40	223.1
18	argon	Ar	g	40.0	1.66^{40K}	84	87	1.21	6.53	154.8
19	potassium	K	s	39.1	0.86	337	1047	2.40	77.5	64.1
20	calcium	Ca	s	40.1	1.55	1112	1757	9.33	150.0	41.4
21	scandium	Sc	s	45.0	2.99	1814	3104	15.9	304.8	34.6
22	titanium	Ti	s	47.9	4.54	1933	3560	20.9	428.9	30.6
23	vanadium	V	s	50.9	6.11	2160	3650	17.6	458.6	28.9
24	chromium	Cr	s	52.0	7.19	2130±20	2945	15.3	348.8	23.5
25	manganese	Mn	s	54.9	7.44	1517	2235	14.4	219.7	32.0
26	iron	Fe	s	55.8	7.87	1808	3023	14.9	351.0	27.3
27	cobalt	Co	s	58.9	8.90	1768	3143	15.2	382.4	30.0
28	nickel	Ni	s	58.7	8.90	1726	3005	17.6	371.8	29.9
29	copper	Cu	s	63.5	8.96	1357	2840	13.0	304.6	33.2
30	zinc	Zn	s	65.4	7.13	693	1180	6.67	115.3	41.6
31	gallium	Ga	s	69.7	5.91	303	2676	5.59	256.1	40.9
32	germanium	Ge	s	72.6	5.32	1211	3103	31.7	334.3	31.1
33	arsenic (grey)	As	s	74.9	5.78	1090^{28atm}	889^{sub}	27.7	31.9	35.1
34	selenium	Se	s	79.0	4.79	490	958	5.1	26.3	42.4
35	bromine	Br	l	79.9	4.05^{123K}	266	332	10.8	30.0	152.2
36	krypton	Kr	g	83.8	2.82^{117K}	117	121	1.64	9.05	164.1

Table 9: Standard enthaply changes of atomisation for some elements

The standard enthalpy change of atomisation ($\Delta H_{at}^{\ominus}$) is the enthalpy change that occurs when 1 mole of atoms in the gaseous state is formed from the element in its standard state, eg:

$Na(s) \rightarrow Na(g)$
$\frac{1}{2}Cl_2(g) \rightarrow Cl(g)$

The values given are 298 K.

Element	$\Delta H_{at}^{\ominus}$/kJ mol^{-1}	Element	$\Delta H_{at}^{\ominus}$/kJ mol^{-1}	Element	$\Delta H_{at}^{\ominus}$/kJ mol^{-1}
H	+218	Al	+330	F	+79
Li	+159	Cu	+337	Cl	+121
Na	+107	Zn	+130	Br	+112
K	+89	Ag	+285	I	+107
Rb	+81	Hg	+61		
Cs	+76	C (graphite)	+717		
Be	+324	Si	+450		
Mg	+147	N	+473		
Ca	+178	P	+317		
Sr	+164	O	+249		
Ba	+180	S	+277		

Table 10: Electronegativity values for some elements on the Pauling scale

The electronegativity of an element is a measure of its ability to attract the electron pair in a covalent bond, relative to that of other elements.

			H 2.2			
Li 1.0	**Be** 1.6	**B** 2.0	**C** 2.6	**N** 3.0	**O** 3.4	**F** 4.0
Na 0.9	**Mg** 1.3	**Al** 1.6	**Si** 1.9	**P** 2.2	**S** 2.6	**Cl** 3.2
K 0.8	**Ca** 1.0					**Br** 3.0
Rb 0.8	**Sr** 1.0					**I** 2.7

Table 11: Ionic radii for some gaseous ions

Positive ions						Negative ions			
Ion	Radius/nm	Ion	Radius/nm	Ion	Radius/nm	Ion	Radius/nm	Ion	Radius/nm
Li^+	0.078					O^{2-}	0.132	F^-	0.133
Na^+	0.098	Mg^{2+}	0.078	Al^{3+}	0.057			Cl^-	0.181
K^+	0.133	Ca^{2+}	0.106					Br^-	0.196
Rb^+	0.149	Sr^{2+}	0.127					I^-	0.220

Table 12: First ionisation enthalpies for the first 36 elements

The first ionisation enthalpy ($\Delta H_i(1)$) is the enthalpy change under standard conditions at 298 K for the reaction

$X(g) \rightarrow X^+(g) + e^-$

Z	Element	$\Delta H_i(1)$/kJ mol^{-1}	Z	Element	$\Delta H_i(1)$/kJ mol^{-1}
1	H	1318	19	K	425
2	He	2379	20	Ca	596
3	Li	519	21	Sc	637
4	Be	905	22	Ti	664
5	B	807	23	V	656
6	C	1092	24	Cr	659
7	N	1407	25	Mn	723
8	O	1320	26	Fe	765
9	F	1687	27	Co	766
10	Ne	2087	28	Ni	743
11	Na	502	29	Cu	751
12	Mg	744	30	Zn	912
13	Al	583	31	Ga	585
14	Si	793	32	Ge	768
15	P	1018	33	As	953
16	S	1006	34	Se	947
17	Cl	1257	35	Br	1146
18	Ar	1526	36	Kr	1357

Ionisation energy represents a change in the internal energy (ΔU) of the process. The data given in this course have been corrected so that the values are given in terms of enthalpy changes.

Table 13: Electron affinities

The first electron affinity ($\Delta H_{EA}^{\ominus}(1)$) of an element is the enthalpy change that occurs when 1 mole of atoms in the gaseous state each gain a single electron to form singly charged ions under standard conditions at 298 K:

$X(g) + e^- \rightarrow X^-(g)$

The second electron affinity ($\Delta H_{EA}^{\ominus}(2)$) refers to the process:

$X^-(g) + e^- \rightarrow X^{2-}(g)$

Element	$\Delta H_{EA}^{\ominus}(1)$/kJ mol^{-1}	$\Delta H_{EA}^{\ominus}(2)$/kJ mol^{-1}	Element	$\Delta H_{EA}^{\ominus}(1)$/kJ mol^{-1}	$\Delta H_{EA}^{\ominus}(2)$/kJ mol^{-1}
H	–73		O	–141	+753
Li	–60		S	–200	+545
Na	–53		F	–328	
K	–48		Cl	–349	
Rb	–47		Br	–324	
Cs	–46		I	–259	
Be	–18		Ne	+29*	
Mg	–21		Ar	+35*	
Ca	–186		Kr	+39*	
Sr	–146		Xe	+41*	
Ba	–46				

* Calculated values

Table 14: Standard enthalpies of hydration of some positive ions (cations)

The enthalpy of hydration ($\Delta H_{hyd}^{\ominus}$) is the enthalpy change for the reaction

$X^{n+}(g) + aq \rightarrow X^{n+}(aq)$

The values quoted refer to formation of a solution of concentration 1 mol dm^{-3} at 298 K.

Ion	$\Delta H_{hyd}^{\ominus}$/kJ mol^{-1}	Ion	$\Delta H_{hyd}^{\ominus}$/kJ mol^{-1}	Ion	$\Delta H_{hyd}^{\ominus}$/kJ mol^{-1}
Li^+	–520				
Na^+	–406	Mg^{2+}	–1926	Al^{3+}	–4680
K^+	–320	Ca^{2+}	–1579		
Rb^+	–296	Sr^{2+}	–1446		

Table 15: Lattice enthalpies for some ionic compounds

The lattice enthalpy ($\Delta H_{LE}^{\ominus}$) is defined in this course as the standard enthalpy change when 1 mole of solid is **formed** from isolated gaseous ions at 298 K. For singly charged ions, it is the enthalpy change for the reaction

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

Using this definition, lattice enthalpies are always negative quantities. (You may see lattice enthalpy defined for the reverse reaction is some books. In this case, it is a positive quantity.)

Compound	$\Delta H_{LE}^{\ominus}$/kJ mol^{-1}	Compound	$\Delta H_{LE}^{\ominus}$/kJ mol^{-1}	Compound	$\Delta H_{LE}^{\ominus}$/kJ mol^{-1}
Li_2O	–2806				
Na_2O	–2488	MgO	–3800	Al_2O_3	–15 916
K_2O	–2245	CaO	–3419		
Rb_2O	–2170	SrO	–3222		
LiF	–1047				
NaF	–928	MgF_2	–2961		
KF	–826	CaF_2	–2634		
LiCl	–862	$MgCl_2$	–2523		
NaCl	–788	$CaCl_2$	–2255		
KCl	–717				

Table 16: Standard molar enthalpy changes of formation ($\Delta H_f^\ominus$) of some inorganic compounds and ions

The values given are at 298 K and 1 atm pressure.

Compound/ion	State	$\Delta H_f^\ominus$/kJ mol^{-1}	Compound/ion	State	$\Delta H_f^\ominus$/kJ mol^{-1}
CO	g	–111	NO	g	+90
CO_2	g	–393	NO_2	g	+33
CO_3^{2-}	aq	–675	HNO_3	l	–174
$CaCO_3$	s	–1207	SO_2	g	–297
Ca^{2+}	aq	–543	SO_3	l	–441
			H_2SO_4	l	–814
H_2O	l	–286	S^{2-}	aq	+33
H_2O	g	–242	SO_4^{2-}	aq	–909
HF	g	–273			
HCl	g	–92			
HBr	g	–36			
HI	g	+26			

Table 17: Solubility products

For a sparingly soluble salt M^+X^- in contact with its saturated solution, the solubility product K_{sp} is given by

$$K_{sp} = [M^+(aq)]\,[X^-(aq)]$$

The values given are at 298 K unless stated otherwise.

Compound	K_{sp}/mol^2 dm^{-6}	Compound	K_{sp}/mol^2 dm^{-6}
AgCl	1.8×10^{-10}	FeS	8.0×10^{-19}
AgBr	5.0×10^{-13}		
AgI	8.3×10^{-17}	$MgCO_3$	2.0×10^{-5}
$BaCO_3$	2.0×10^{-9}	$PbCO_3$	7.4×10^{-14}
BaC_2O_4	1.7×10^{-7}	$PbCrO_4$	2.5×10^{-14}
$BaCrO_4$	2.1×10^{-10}	$PbSO_4$	1.6×10^{-8}
$BaSO_4$	1.1×10^{-10}	PbS	3.0×10^{-28}
$CaCO_3$	3.3×10^{-9}	$SrCO_3$	5.4×10^{-10}
CaC_2O_4	2.3×10^{-9}		
$CaSO_4$	2.4×10^{-5}	$ZnCO_3$	1.4×10^{-11}

Table 18: K_a and pK_a values for some weak acids

For a weak acid HA, the acidity constant K_a is given by

$$K_a = \frac{[H^+(aq)]\,[A^-(aq)]}{[HA(aq)]} \quad \text{and} \quad pK_a = -\lg K_a$$

The values given are at 298 K.

Acid	Formula	K_a/mol dm^{-3}	pK_a
methanoic	HCOOH	1.6×10^{-4}	3.8
ethanoic	CH_3COOH	1.7×10^{-5}	4.8
propanoic	CH_3CH_2COOH	1.3×10^{-5}	4.9
1-butanoic	$CH_3CH_2CH_2COOH$	1.5×10^{-5}	4.8
benzoic	C_6H_5COOH	6.3×10^{-5}	4.2
chloric(I)	HClO	3.7×10^{-8}	7.4
hydrocyanic	HCN	4.9×10^{-10}	9.3
nitrous (nitric(III))	HNO_2	4.7×10^{-4}	3.3

Table 19: Organic compounds: physical and thermochemical data

St — Normal physical state at 298 K and 1 atm pressure (s, solid; l, liquid; g, gas)
M — Molar mass of the compound
ρ — Density at 298 K and 1 atm pressure (or density of liquid at T_b for gases)
T_m — Melting point } at 1 atm pressure
T_b — Boiling point } at 1 atm pressure
$\Delta H_c^\ominus$ — Standard molar enthalpy change of combustion at 298 K
$\Delta H_f^\ominus$ — Standard molar enthalpy change of formation at 298 K

Compound	Formula	St	M/g mol^{-1}	ρ/g cm^{-3}	T_m/K	T_b/K	$\Delta H_c^\ominus$/kJ mol^{-1}	$\Delta H_f^\ominus$/kJ mol^{-1}
Straight-chain alkanes								
methane	CH_4	g	16.0	0.466^{liq}	90.5	111.5	–890	–74.8
ethane	CH_3CH_3	g	30.1	0.572^{liq}	89.7	184.4	–1560	–84.7
propane	$CH_3CH_2CH_3$	g	44.1	0.585^{liq}	85.3	230.9	–2220	–104
butane	$CH_3(CH_2)_2CH_3$	g	58.1	0.601^{liq}	134.6	272.5	–2877	–126
pentane	$CH_3(CH_2)_3CH_3$	l	72.1	0.621	143.3	309.1	–3509	–173
hexane	$CH_3(CH_2)_4CH_3$	l	86.2	0.655	177.7	341.7	–4163	–199
heptane	$CH_3(CH_2)_5CH_3$	l	100.2	0.680	182.4	371.4	–4817	–224
octane	$CH_3(CH_2)_6CH_3$	l	114.2	0.698	216.2	398.7	–5470	–250
nonane	$CH_3(CH_2)_7CH_3$	l	128.3	0.714	219.5	423.8	–6125	–275
decane	$CH_3(CH_2)_8CH_3$	l	142.3	0.726	243.3	447.1	–6778	–301
undecane	$CH_3(CH_2)_9CH_3$	l	156.3	0.737	247.4	468.9	–7431	–327
dodecane	$CH_3(CH_2)_{10}CH_3$	l	170.3	0.745	263.4	489.3	–8089	–351
eicosane	$CH_3(CH_2)_{18}CH_3$	s	282.5	0.785	309.4	616.8	–13300	–
Branched alkanes								
2-methylpropane	$(CH_3)_2CHCH_3$	g	58.1	0.551^{liq}	113.4	261.3	–2868	–135
2-methylbutane	$(CH_3)_2CHCH_2CH_3$	l	72.2	0.615	113.1	300.9	–3504	–179
2-methylpentane	$(CH_3)_2CH(CH_2)_2CH_3$	l	86.2	0.649	119.3	333.3	–4157	–205
2-methylhexane	$(CH_3)_2CH(CH_2)_3CH_3$	l	100.2	0.679	154.8	363.1	–4811	–230
2-methylheptane	$(CH_3)_2CH(CH_2)_4CH_3$	l	114.2	0.698	164.1	390.7	–5465	–255
2,2-dimethylpropane	$C(CH_3)_4$	g	72.2	0.585^{liq}	256.4	282.5	–3514	–190
Cycloalkanes								
cyclopropane	$(CH_2)_3$	g	42.1	0.720^{liq}	145.6	240.2	–2091	+53
cyclobutane	$(CH_2)_4$	g	56.1	0.689^{liq}	182.3	285.5	–2746	+27
cyclopentane	$(CH_2)_5$	l	70.1	0.740	179.1	322.3	–3291	–107
cyclohexane	$(CH_2)_6$	l	84.2	0.774	279.6	353.7	–3920	–156
cycloheptane	$(CH_2)_7$	l	98.2	0.810	261.1	391.6	–4598	–157
cyclooctane	$(CH_2)_8$	l	112.2	0.835	287.4	421.1	–5267	–168
Alcohols								
methanol	CH_3OH	l	32.0	0.787	175.3	337.7	–726	–239
ethanol	CH_3CH_2OH	l	46.1	0.785	158.9	351.3	–1367	–277
propan-1-ol	$CH_3CH_2CH_2OH$	l	60.1	0.799	146.8	370.2	–2021	–303
propan-2-ol	$CH_3CH(OH)CH_3$	l	60.1	0.781	184.5	355.3	–2006	–317
butan-1-ol	$CH_3(CH_2)_2CH_2OH$	l	74.1	0.806	183.7	390.7	–2676	–327
pentan-1-ol	$CH_3(CH_2)_3CH_2OH$	l	88.2	0.811	194.8	411.0	–3331	–354
hexan-1-ol	$CH_3(CH_2)_4CH_2OH$	l	102.2	0.816	228.4	430.1	–3984	–378
heptan-1-ol	$CH_3(CH_2)_5CH_2OH$	l	116.2	0.819	239.0	449.2	–4638	–403
octan-1-ol	$CH_3(CH_2)_6CH_2OH$	l	130.2	0.822	258.1	468.2	–5294	–427
ethane-1,2-diol	$CH_2(OH)CH_2OH$	l	62.1	1.109	257.4	471.1	–1189	–455
propane-1,2,3-triol	$CH_2(OH)CH(OH)CH_2OH$	l	92.1	1.260	293.1	563.1	–1655	–669
2-methylpropan-2-ol	$(CH_3)_3COH$	l	74.1	0.781	298.7	355.6	–2644	–359
cyclohexanol	$CH_2(CH_2)_4CHOH$	s	100.2	0.962	298.2	434.0	–3728	–349
Carboxylic acids								
methanoic (formic)	$HCOOH$	l	46.0	1.214	281.4	373.6	–254	–425
ethanoic (acetic)	CH_3COOH	l	60.1	1.044	289.7	390.9	–874	–485
propanoic	CH_3CH_2COOH	l	74.1	0.998	252.3	413.8	–1527	–511
butanoic	$CH_3CH_2CH_2COOH$	l	88.1	0.952	267.3	436.3	–2183	–534

Table 20: Bond lengths and bond enthalpies

L Bond length
E(X–Y) Bond enthalpy at 298 K and 1 atm pressure

Bond	*L*/nm	*E*(X–Y)/kJ mol^{-1}	Bond	*L*/nm	*E*(X–Y)/kJ mol^{-1}
Br—Br	0.228	192.9	O—O (in O_3)	0.128	302
Br—H	0.141	366.3	O═O	0.121	498.3
Cl—Cl	0.199	243.4	Si—Si	0.235	226
Cl—H	0.127	432.0	O—Si	0.161	466
F—F	0.142	158	P—P (in P_4)	0.221	198
F—H	0.092	568.0	P≡P (in P_2)	0.189	485
I—I	0.267	151.2	C—C*	0.154	347
H—I	0.161	298.3	C═C*	0.134	612
H—H	0.074	435.9	C≡C*	0.120	838
H—Si	0.148	318	C—H*	0.108	413
H—N	0.101	391	C—F*	0.138	467
H—P	0.144	321	C—Cl*	0.177	346
H—O	0.096	464	C—Br*	0.194	290
H—S	0.134	364	C—I*	0.214	228
N—N	0.145	158	C—O*	0.143	358
N═N	0.120	410	C—O (in CH_3OH)	0.143	336
N≡N	0.110	945.4	C═O (in CO_2)	0.116	805
O—O (in H_2O_2)	0.148	144	C═0*	0.123	745

* Average bond enthalpies

Table 21: Standard electrode potentials

The values given are at 298 K.

Half-reaction		$E^{\ominus}$/V
least oxidising	**most reducing**	
↓	↓	
$Li^+(aq) + e^-$	→ $Li(s)$	–3.04
$K^+(aq) + e^-$	→ $K(s)$	–2.92
$Ca^{2+}(aq) + 2e^-$	→ $Ca(s)$	–2.84
$Na^+(aq) + e^-$	→ $Na(s)$	–2.71
$Mg^{2+}(aq) + 2e^-$	→ $Mg(s)$	–2.36
$Al^{3+}(aq) + 3e^-$	→ $Al(s)$	–1.68
$Zn^{2+}(aq) + 2e^-$	→ $Zn(s)$	–0.76
$Fe^{2+}(aq) + 2e^-$	→ $Fe(s)$	–0.44
$Ni^{2+}(aq) + 2e^-$	→ $Ni(s)$	–0.26
$Sn^{2+}(aq) + 2e^-$	→ $Sn(s)$	–0.14
$Pb^{2+}(aq) + 2e^-$	→ $Pb(s)$	–0.13
$2H^+(aq) + 2e^-$	→ $H_2(g)$	0.00
$Sn^{4+}(aq) + 2e^-$	→ $Sn^{2+}(aq)$	+0.15
$Cu^{2+}(aq) + 2e^-$	→ $Cu(s)$	+0.34
$O_2(g)+2H_2O(l) + 4e^-$	→ $4OH^-(aq)$	+0.40
$Cu^+(aq) + e^-$	→ $Cu(s)$	+0.52
$I_2(aq) + 2e^-$	→ $2I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^-$	→ $Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^-$	→ $Ag(s)$	+0.80
$Br_2(aq) + 2e^-$	→ $2Br^-(aq)$	+1.07
$O_2(g) + 4H^+(aq) + 4e^-$	→ $2H_2O(aq)$	+1.23
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	→ $2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$Cl_2(aq) + 2e^-$	→ $2Cl^-(aq)$	+1.36
$MnO_4^-(aq) + 8H^+(aq) + 5e^-$	→ $Mn^{2+}(aq) + 4H_2O(l)$	+1.51
↑	↑	
most oxidising	**least reducing**	

Table 22: Characteristic i.r. absorptions in organic molecules

M Medium
S Strong
* hydrogen-bonded

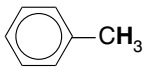
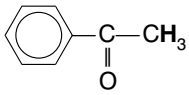
Bond	Location	Wavenumber/cm^{-1}	Intensity
C—H	alkanes	2850–2950	M–S
	alkenes, arenes	3000–3100	M–S
	alkynes	*ca* 3300	S
C═C	alkenes	1620–1680	M
	arenes	several peaks in range 1450–1650	variable
C≡C	alkynes	2100–2260	M
C═O	aldehydes	1720–1740	S
	ketones	1705–1725	S
	carboxylic acids	1700–1725	S
	esters	1735–1750	S
	amides	1630–1700	M
C—O	alcohols, ethers, esters	1050–1300	S
C≡N	nitriles	2200–2260	M
C—F	fluoroalkanes	1000–1400	S
C—Cl	chloroalkanes	600–800	S
C—Br	bromoalkanes	500–600	S
O—H	alcohols, phenols	3600–3640	S
	*alcohols, phenols	3200–3600	S (broad)
	*carboxylic acids	2500–3200	M (broad)
N—H	primary amines	3300–3500	M–S
	amides	*ca* 3500	M

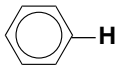
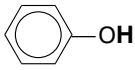
Table 23: Chemical shifts for some types of protons (^1H) in n.m.r. spectra

Chemical shifts are for hydrogen (^1H) relative to TMS (tetramethylsilane).
Chemical shift (δ) in ppm from TMS is given by

$$\frac{B_{TMS} - B_{sample}}{B_{TMS}} \times 10^6$$

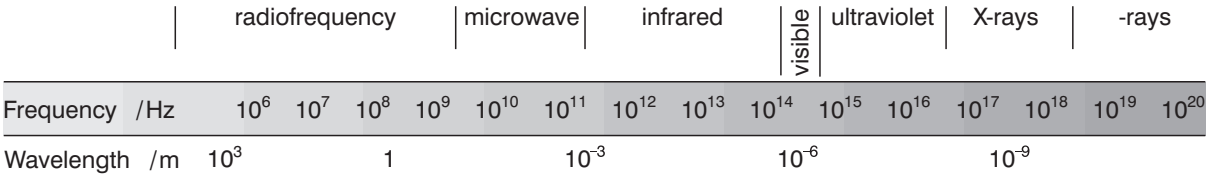
where B is the strength of the applied magnetic field at resonance.
R represents an alkyl group

Type of proton		Chemical shift (δ) in approximate region of
R—CH_3		0.8–1.2
R—CH_2—R		1.4
R—CH(R)—R		1.5
>C=C(—)—CH_3		1.6
>C=C(—)—CH_2—R		2.3
		2.3
R—C(=O)—CH_3		2.2
R—C(=O)—CH_2—R		2.4
		2.6
>N—CH_3	(amine)	2.3
>N—CH_2—R	(amine)	2.5
R—C(=O)—N(—)—CH_3	(amide)	2.9

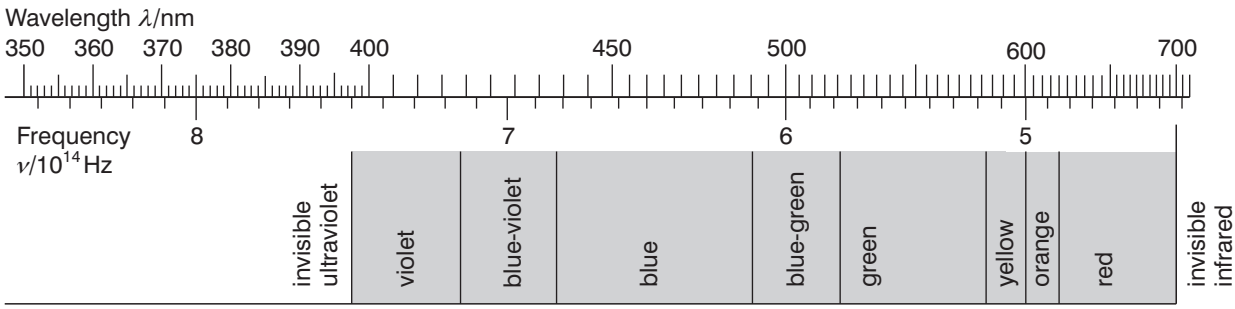
Type of proton		Chemical shift (δ) in approximate region of
—O—CH_3	(alcohol)	3.3
—O—CH_2—R	(alcohol)	3.6
R—C(=O)—O—CH_3	(ester)	3.7
R—CH_2—Cl		3.6
R—CH_2—Br		3.5
R—CH=CH—R		4.5–6.0
R—CH=CH—C(=O)—		6.0–8.0
		6.0–9.0
R—C(—)(=O)	(aldehyde)	10.0
R—OH		0.5–4.5*
		4.5–10.0*
R—NH_2	(amine)	0.5–6.0*
R—C(=O)—NH_2	(amide)	5–12*
R—C(=O)—OH	(acid)	9–15*

* Signals from hydrogens in —OH and —NH— groups in alcohols, phenols, carboxylic acids, amines and amides are very variable and often broad. The chemical shift is sensitive to temperature, nature of the solvent and the concentration. The stronger the hydrogen bonding the larger the chemical shift.

Table 24: The electromagnetic spectrum



Enlargement of visible region



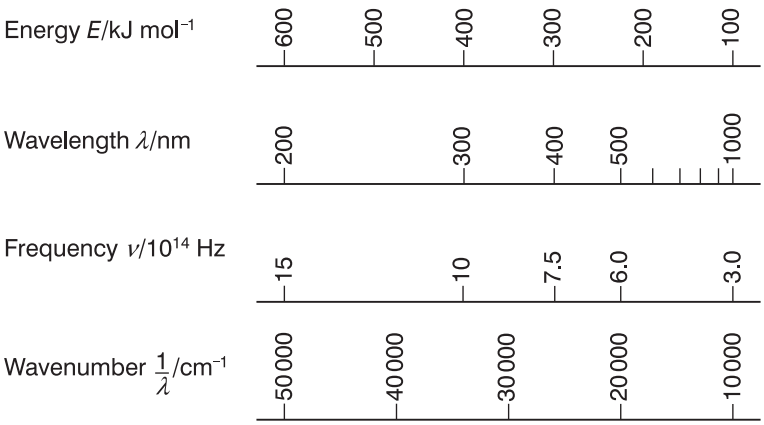
Converting frequencies to wavelengths

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8\,\mathrm{m\,s^{-1}}}{\nu}$$

For λ measured in nm and ν in $\mathrm{s^{-1}}$(Hz)

$$\lambda = \frac{3.00 \times 10^{17}\,\mathrm{nm\,s^{-1}}}{\nu}$$

Relationship between energy, wavelength, frequency and wavenumber



Regions of ultraviolet radiation

u.v. (A): 400 nm–320 nm
u.v. (B): 320 nm–280 nm
u.v. (C): < 280 nm