SECTION 8

ELECTROLYTES, ELECTROMOTIVE FORCE, AND CHEMICAL EQUILIBRIUM

8.1 ACTIVITY COEFFICIENTS

Although it is not possible to measure an individual ionic activity coefficient, f_i, it may be estimated from the following equation of the Debye-Hückel theory:

$$-\log f_i = \frac{Az_i^2\sqrt{I}}{1 + B\mathring{a}\sqrt{I}}$$

where I is the ionic strength of the medium, and $\mathring{a}$ is the ion-size parameter—the effective ionic radius (Table 8.2). The values of A and B vary with the temperature and dielectric constant of the solvent; values from 0 to 100°C for aqueous medium ($\mathring{a}$ in angstrom units) are listed in Table 8.3. Corresponding values of A and B for unit weight of solvent (when employing molality) can be obtained by multiplying the corresponding values for unit volume (molarity units) by the square root of the density of water at the appropriate temperature.

The ionic strength can be estimated from the summation of the product molarity times ionic charge squared for all the ionic species present in the solution, i.e., $I = 0.5(c_1z_1^2 + c_2z_2^2 + \cdots + c_iz_i^2)$.

Values for the activity coefficients of ions in water at 25°C are given in Table 8.1 in terms of their effective ionic radii.

At moderate ionic strengths a considerable improvement is effected by subtracting a term bI from the Debye-Hückel expression; b is an adjustable parameter which is 0.2 for water at 25°C. Table 8.4 gives the values of the ionic activity coefficients (for z_i from 1 to 6) with $\mathring{a}$ taken to be 4.6Å.

In general, the mean ionic activity coefficient is given by

$$f_{\pm} = \sqrt[(x+y)]{f_+^x f_-^y}$$

TABLE 8.1 Individual Activity Coefficients of Ions in Water at 25°C

Effective Ionic Radii $å$ (in Å)	f_i at Ionic Strength of				
	0.001	0.005	0.01	0.05	0.1
Univalent Ions					
9	0.967	0.933	0.914	0.86	0.83
8	0.966	0.931	0.912	0.85	0.82
7	0.965	0.930	0.909	0.845	0.81
6	0.965	0.929	0.907	0.835	0.80
5	0.964	0.928	0.904	0.83	0.79
4	0.964	0.928	0.902	0.82	0.775
3.5	0.964	0.926	0.900	0.81	0.76
3	0.964	0.925	0.899	0.805	0.755
2.5	0.964	0.924	0.898	0.80	0.75
Divalent Ions					
8	0.872	0.755	0.69	0.52	0.45
7	0.872	0.755	0.685	0.50	0.425
6	0.870	0.749	0.675	0.485	0.405
5	0.868	0.744	0.67	0.465	0.38
4.5	0.868	0.741	0.663	0.45	0.36
4	0.867	0.740	0.660	0.445	0.355
Trivalent Ions					
6	0.731	0.52	0.415	0.195	0.13
5	0.728	0.51	0.405	0.18	0.115
4	0.725	0.505	0.395	0.16	0.095
Tetravalent Ions					
11	0.588	0.35	0.255	0.10	0.065
5	0.57	0.31	0.20	0.048	0.021
Pentavalent Ions					
9	0.43	0.18	0.105	0.020	0.009

where f_+, f_- are the individual ionic activity coefficients, and x,y are the charge numbers (z_+, z_-) of the respective ions. In binary electrolyte solution.

$$f_\pm = \sqrt{f_+ f_-}$$

In ternary electrolytes, e.g., $BaCl_2$ or K_2SO_4,

$$f_\pm = \sqrt[3]{f_+ f_-^2} \quad \text{or} \quad f_\pm = \sqrt[3]{f_+^2 f_-}$$

In quaternary electrolytes, e.g., $LaCl_3$ or $K_3[Fe(CN)_6]$,

$$f_\pm = \sqrt[4]{f_+ f_-^3} \quad \text{or} \quad f_\pm = \sqrt[4]{f_+^3 f_-}$$

TABLE 8.2 Approximate Effective Ionic Radii in Aqueous Solutions at 25°C

å (in Å)	Inorganic Ions	*å* (in Å)	Organic Ions
2.5	Rb^+, Cs^+, NH_4^+, Tl^+, Ag^+	3.5	$HCOO^-$, H_2Cit^-, $CH_3NH_3^+$, $(CH_3)_2NH_2^+$
3	K^+, Cl^-, Br^-, I^-, CN^-, NO_2^-, NO_3^-	4	$H_3N^+CH_2COOH$, $(CH_3)_3NH^+$, $C_2H_5NH_3^+$
3.5	OH^-, F^-, SCN^-, OCN^-, HS^-, ClO_3^-, ClO_4^-, BrO_3^-, IO_4^-, MnO_4^-	4.5	CH_3COO^-, $ClCH_2COO^-$, $(CH_3)_4N^+$, $(C_2H_5)_2NH_2^+$, $H_2NCH_2COO^-$, oxalate^{2-}, $HCit^{2-}$
4	Na^+, $CdCl^+$, Hg_2^{2+}, ClO_2^-, IO_3^-, HCO_3^-, $H_2PO_4^-$, HSO_3^-, $H_2AsO_4^-$, SO_4^{2-}, $S_2O_3^{2-}$, $S_2O_8^{2-}$, SeO_4^{2-}, CrO_4^{2-}, HPO_4^{2-}, $S_2O_6^{2-}$, PO_4^{3-}, $Fe(CN)_6^{3-}$, $Cr(NH_3)_6^{3+}$, $Co(NH_3)_6^{3+}$, $Co(NH_3)_5H_2O^{3+}$	5	Cl_2CHCOO^-, Cl_3COO^-, $(C_2H_5)_3NH^+$, $C_3H_7NH_3^+$, Cit^{3-}, succinate^{2-}, malonate^{2-}, tartrate^{2-}
4.5	Pb^{2+}, CO_3^{2-}, SO_3^{2-}, MoO_4^{2-}, $Co(NH_3)_5Cl^{2+}$, $Fe(CN)_5NO^{2-}$	6	benzoate$^-$, hydroxybenzoate$^-$, chlorobenzoate$^-$, phenylacetate$^-$, vinylacetate$^-$, $(CH_3)_2C{=}CHCOO^-$, $(C_2H_5)_4N^+$, $(C_3H_7)_2NH_2^+$, phthalate^{2-}, glutarate^{2-}, adipate^{2-}
5	Sr^{2+}, Ba^{2+}, Ra^{2+}, Cd^{2+}, Hg^{2+}, S^{2-}, $S_2O_4^{2-}$, WO_4^{2-}, $Fe(CN)_6^{4-}$	7	trinitrophenolate$^-$, $(C_3H_7)_3NH^+$, methoxybenzoate$^-$, pimelate^{2-}, suberate^{2-}, Congo red anion^{2-}
6	Li^+, Ca^{2+}, Cu^{2+}, Zn^{2+}, Sn^{2+}, Mn^{2+}, Fe^{2+}, Ni^{2+}, Co^{2+}, $Co(en)_3^{3+}$, $Co(S_2O_3)(CN)_5^{4-}$	8	$(C_6H_5)_2CHCOO^-$, $(C_3H_7)_4N^+$
8	Mg^{2+}, Be^{2+}		
9	H^+, Al^{3+}, Fe^{3+}, Cr^{3+}, Sc^{3+}, Y^{3+}, La^{3+}, In^{3+}, Ce^{3+}, Pr^{3+}, Nd^{3+}, Sm^{3+}, $Co(SO_3)_2(CN)_4^{5-}$		
11	Th^{4+}, Zr^{4+}, Ce^{4+}, Sn^{4+}		

TABLE 8.3 Constants of the Debye-Hückel Equation from 0 to 100°C

$$-\log f_i = \frac{Az_i^2\sqrt{I}}{1 + B\mathring{a}\sqrt{I}}$$

Temp., °C	Unit Volume of Solvent		Temp., °C	Unit Volume of Solvent	
	A	*B*		*A*	*B*
0	0.4918	0.3248	55	0.5432	0.3358
5	0.4952	0.3256	60	0.5494	0.3371
10	0.4989	0.3264	65	0.5558	0.3384
15	0.5028	0.3273	70	0.5625	0.3397
20	0.5070	0.3282	75	0.5695	0.3411
25	0.5115	0.3291	80	0.5767	0.3426
30	0.5161	0.3301	85	0.5842	0.3440
35	0.5211	0.3312	90	0.5920	0.3456
40	0.5262	0.3323	95	0.6001	0.3471
45	0.5317	0.3334	100	0.6086	0.3488
50	0.5373	0.3346			

The values for unit weight of solvent (molality scale) can be obtained by multiplying the corresponding values for unit volume by the square root of the density of water at the appropriate temperature.

TABLE 8.4 Individual Ionic Activity Coefficients at Higher Ionic Strengths at 25°C

The values were calculated from the modified Debye-Hückel equation utilizing the modifications proposed by Robinson and by Guggenheim and Bates:

$$-\frac{\log f_i}{z_i^2} = \frac{0.511I}{1 + 1.5I} - 0.2I$$

where I is the ionic strength and $\mathring{a}$ is assumed to be 4.6 Å.

I	$-\frac{\log_{10} f_i}{z_i^2}$	f_i for z_i =					
		1	2	3	4	5	6
0.05	0.0756	0.840	0.498	0.209	0.0617	0.0129	0.00190
0.1	0.0896	0.814	0.438	0.156	0.0369	0.00576	0.000595
0.2	0.0968	0.800	0.410	0.138	0.0283	0.00380	0.000328
0.3	0.0936	0.806	0.422	0.144	0.0318	0.00457	0.000427
0.4	0.0858	0.821	0.454	0.169	0.0424	0.00716	0.000815
0.5	0.0753	0.841	0.500	0.210	0.0624	0.0131	0.00195
0.6	0.0631	0.865	0.559	0.270_5	0.0978	0.0265	0.00535
0.7	0.0496	0.892	0.633	0.358	0.161	0.0575_5	0.0164
0.8	0.0352	0.922	0.723	0.482	0.273	0.132	0.0541
0.9	0.0201	0.955	0.831	0.659	0.477	0.314	0.189
1.0	0.0044	0.900	0.960	0.913	0.850	0.776	0.694

8.2 EQUILIBRIUM CONSTANTS

TABLE 8.5 Ionic Product Constant of Water

This table gives values of p*Kw* on a molal scale, where *Kw* is the ionic activity product constant of water. Values are from W. L. Marshall and E. U. Franck, *J. Phys. Chem. Ref. Data*, **10:**295 (1981).

Temp., °C	p*Kw*	Temp., °C	p*Kw*	Temp., °C	p*Kw*
0	14.938	45	13.405	95	12.345
5	14.727	50	13.275	100	12.264
10	14.528	55	13.152	125	11.911
15	14.340	60	13.034	150	11.637
18	14.233	65	12.921	175	11.431
20	14.163	70	12.814	200	11.288
25	13.995	75	12.711	225	11.207
30	13.836	80	12.613	250	11.192
35	13.685	85	12.520	275	11.251
40	13.542	90	12.431	300	11.406

TABLE 8.6 Solubility Product Constants

The data refer to various temperatures between 18 and 25°C, and were compiled from values cited by Bjerrum, Schwarzenbach, and Sillen, *Stability Constants of Metal Complexes*, part II, Chemical Society, London, 1958, and values taken from publications of the IUPAC Solubility Data Project: *Solubility Data Series*, International Union of Pure and Applied Chemistry, Pergamon Press, Oxford, 1979–1992; H. L. Clever, and F. J. Johnston, *J. Phys. Chem. Ref. Data,* **9:**751 (1980); Y. Marcus, *Ibid.* **9:**1307 (1980); H. L. Clever, S. A. Johnson, and M. E. Derrick, *Ibid.* **14:**631 (1985), and **21:**941 (1992).

In the table, "L" is the abbreviation of the organic ligand.

Compound	Formula	pK_{sp}	K_{sp}
Actinium			
hydroxide	$Ac(OH)_3$	15	1×10^{-15}
Aluminum			
arsonate	$AlAsO_4$	15.80	1.6×10^{-16}
cupferrate	AlL_3	18.64	2.3×10^{-19}
hydroxide	$Al(OH)_3$	32.89	1.3×10^{-33}
phosphate	$AlPO_4$	20.01	9.84×10^{-21}
8-quinolinolate	AlL_3	29.00	1.00×10^{-29}
selenide	Al_2Se_3	24.4	4×10^{-25}
sulfide	Al_2S_3	6.7	2×10^{-7}
Americium			
(III) hydroxide	$Am(OH)_3$	19.57	2.7×10^{-20}
(IV) hydroxide	$Am(OH)_4$	56	1×10^{-56}
Ammonium			
uranyl arsenate	$NH_4UO_2AsO_4$	23.77	1.7×10^{-24}
Arsenic			
(III) sulfide	As_2S_3	21.68	2.1×10^{-22}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
Barium			
arsenate	$Ba_3(AsO_4)_2$	50.11	8.0×10^{-51}
bromate	$Ba(BrO_3)_2$	5.50	2.43×10^{-4}
carbonate	$BaCO_3$	8.59	2.58×10^{-9}
chromate	$BaCrO_4$	9.93	1.17×10^{-10}
ferricyanide 6-hydrate	$Ba_2[Fe(CN)_6] \cdot 6H_2O$	7.49	3.2×10^{-8}
fluoride	BaF_2	6.74	1.84×10^{-7}
hexafluorosilicate	$BaSiF_6$	6	1×10^{-6}
hydrogen phosphate	$BaHPO_4$	6.49	3.2×10^{-7}
hydroxide 8-hydrate	$Ba(OH)_2 \cdot 8H_2O$	3.59	2.55×10^{-4}
iodate hydrate	$Ba(IO_3)_2 \cdot H_2O$	8.40	4.01×10^{-9}
molybdate	$BaMoO_4$	7.45	3.54×10^{-8}
niobate	$Ba(NbO_3)_2$	16.50	3.2×10^{-17}
nitrate	$Ba(NO_3)_2$	2.33	4.64×10^{-3}
oxalate	BaC_2O_4	6.79	1.6×10^{-7}
oxalate hydrate	$BaC_2O_4 \cdot H_2O$	7.64	2.3×10^{-8}
permanganate	$Ba(MnO_4)_2$	9.61	2.5×10^{-10}
perrhenate	$Ba(ReO_4)_2$	1.28	5.2×10^{-2}
phosphate	$Ba_3(PO_4)_2$	22.47	3.4×10^{-23}
pyrophosphate	$Ba_2P_2O_7$	10.50	3.2×10^{-11}
8-quinolinolate	BaL_2	8.30	5.0×10^{-9}
selenate	$BaSeO_4$	7.47	3.40×10^{-8}
sulfate	$BaSO_4$	9.97	1.08×10^{-10}
sulfite	$BaSO_3$	9.30	5.0×10^{-10}
thiosulfate	BaS_2O_3	4.79	1.6×10^{-5}
Beryllium			
carbonate 4-hydrate	$BeCO_3 \cdot 4H_2O$	3	1×10^{-3}
hydroxide (amorphous)	$Be(OH)_2$	21.16	6.92×10^{-22}
molybdate	$BeMoO_4$	1.49	3.2×10^{-2}
niobate	$Be(NbO_3)_2$	15.92	1.2×10^{-16}
Bismuth			
arsenate	$BiAsO_4$	9.35	4.43×10^{-10}
cupferrate	BiL_3	27.22	6.0×10^{-28}
hydroxide	$Bi(OH)_3$	30.4	6.0×10^{-31}
iodide	BiI_3	18.11	7.71×10^{-19}
oxide bromide	BiOBr	6.52	3.0×10^{-7}
oxide chloride	BiOCl	30.75	1.8×10^{-31}
oxide hydroxide	BiO(OH)	9.4	4×10^{-10}
oxide nitrate	$BiO(NO_3)$	2.55	2.82×10^{-3}
oxide nitrite	$BiO(NO_2)$	6.31	4.9×10^{-7}
oxide thiocyanate	BiO(SCN)	6.80	1.6×10^{-7}
phosphate	$BiPO_4$	22.89	1.3×10^{-23}
sulfide	Bi_2S_3	97	1×10^{-97}
Cadmium			
anthranilate	CdL_2	8.27	5.4×10^{-9}
arsenate	$Cd_3(AsO_4)_2$	32.66	2.2×10^{-33}
benzoate 2-hydrate	$CdL_2 \cdot 2H_2O$	2.7	2×10^{-3}
borate, *meta*	$Cd(BO_2)_2$	8.64	2.3×10^{-9}
carbonate	$CdCO_3$	12.0	1.0×10^{-12}
cyanide	$Cd(CN)_2$	8.0	1.0×10^{-8}
ferrocyanide	$Cd_2[Fe(CN)_6]$	16.49	3.2×10^{-17}
fluoride	CdF_2	2.19	6.44×10^{-3}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
hydroxide	$Cd(OH)_2$ fresh	14.14	7.2×10^{-15}
iodate	$Cd(IO_3)_2$	7.60	2.5×10^{-8}
oxalate 3-water	$CdC_2O_4 \cdot 3H_2O$	7.85	1.42×10^{-8}
phosphate	$Cd_3(PO_4)_2$	32.60	2.53×10^{-33}
quinaldate	CdL_2	12.30	5.0×10^{-13}
sulfide	CdS	26.10	8.0×10^{-27}
tungstate	$CdWO_4$	5.7	2×10^{-6}
Calcium			
acetate 3-water	$Ca(OAc)_2 \cdot 3H_2O$	2.4	4×10^{-3}
arsenate	$Ca_3(AsO_4)_2$	18.17	6.8×10^{-19}
benzoate 3-water	$CaL_2 \cdot 3H_2O$	2.4	4×10^{-3}
carbonate	$CaCO_3$	8.54	2.8×10^{-9}
carbonate (calcite)	$CaCO_3$	8.47	3.36×10^{-9}
carbonate (aragonite)	$CaCO_3$	8.22	6.0×10^{-9}
carbonatomagnesium	$Ca[Mg(CO_3)_2]$ dolomite	11	1×10^{-11}
chromate	$CaCrO_4$	3.15	7.1×10^{-4}
fluoride	CaF_2	8.28	5.3×10^{-9}
hexafluorosilicate	$Ca[SiF_6]$	3.09	8.1×10^{-4}
hydrogen phosphate	$CaHPO_4$	7.0	1.0×10^{-7}
hydroxide	$Ca(OH)_2$	5.26	5.5×10^{-6}
iodate 6-water	$Ca(IO_3)_2 \cdot 6H_2O$	6.15	7.10×10^{-7}
molybdate	$CaMoO_4$	7.84	1.46×10^{-8}
niobate	$Ca(NbO_3)_2$	17.06	8.7×10^{-18}
oxalate hydrate	$CaC_2O_4 \cdot H_2O$	8.63	2.32×10^{-9}
phosphate	$Ca_3(PO_4)_2$	28.68	2.07×10^{-29}
8-quinolinolate	CaL_2	11.12	7.6×10^{-12}
selenate	$CaSeO_4$	3.09	8.1×10^{-4}
selenite	$CaSeO_3$	5.53	8.0×10^{-6}
silicate, *meta*	$CaSiO_3$	7.60	2.5×10^{-8}
sulfate	$CaSO_4$	4.31	4.93×10^{-5}
sulfate dihydrate	$CaSO_4 \cdot 2H_2O$	4.50	3.14×10^{-5}
sulfite	$CaSO_3$	7.17	6.8×10^{-8}
sulfite 0.5-water	$CaSO_3 \cdot 0.5H_2O$	6.51	3.1×10^{-7}
tartrate dihydrate	$CaL \cdot 2H_2O$	6.11	7.7×10^{-7}
tungstate	$CaWO_4$	8.06	8.7×10^{-9}
Cerium			
(III) fluoride	CeF_3	15.1	8×10^{-16}
(III) hydroxide	$Ce(OH)_3$	19.80	1.6×10^{-20}
(IV) hydroxide	$Ce(OH)_4$	47.7	2×10^{-48}
(III) iodate	$Ce(IO_3)_3$	9.50	3.2×10^{-10}
(IV) iodate	$Ce(IO_3)_4$	16.3	5×10^{-17}
(III) oxalate 9-water	$Ce_2(C_2O_4)_3 \cdot 9H_2O$	25.50	3.2×10^{-26}
(III) phosphate	$CePO_4$	23	1×10^{-23}
(III) selenite	$Ce_2(SeO_3)_3$	24.43	3.7×10^{-25}
(III) sulfide	Ce_2S_3	10.22	6.0×10^{-11}
(III) tartrate	Ce_2L_3	19.0	1.0×10^{-19}
Cesium			
bromate	$CsBrO_3$	1.7	5×10^{-2}
chlorate	$CsClO_3$	1.4	4×10^{-2}
cobaltihexanitrite	$Cs_3[Co(NO_2)_6]$	15.24	5.7×10^{-16}
hexachloroplatinate(IV)	$Cs_2[PtCl_6]$	7.50	3.2×10^{-8}
hexafluoroplatinate(IV)	$Cs_2[PtF_6]$	5.62	2.4×10^{-6}
hexafluorosilicate	$Cs_2[SiF_6]$	4.90	1.3×10^{-5}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
perchlorate	$CsClO_4$	2.40	3.95×10^{-3}
periodate	$CsIO_4$	5.29	5.16×10^{-6}
permanganate	$CsMnO_4$	4.08	8.2×10^{-5}
perrhanate	$CsReO_4$	3.40	4.0×10^{-4}
tetrafluoroborate	$Cs[BF_4]$	4.7	5×10^{-5}
Chromium(II)			
hydroxide	$Cr(OH)_2$	15.7	2×10^{-16}
Chromium(III)			
arsenate	$CrAsO_4$	20.11	7.7×10^{-21}
fluoride	CrF_3	10.18	6.6×10^{-11}
hydroxide	$Cr(OH)_3$	30.20	6.3×10^{-31}
phosphate 4-water	$CrPO_4 \cdot 4H_2O$ green	22.62	2.4×10^{-23}
	violet	17.00	1.0×10^{-17}
Cobalt			
anthranilate	CoL_2	9.68	2.1×10^{-10}
arsenate	$Co_3(AsO_4)_2$	28.17	6.80×10^{-29}
carbonate	$CoCO_3$	12.84	1.4×10^{-13}
ferrocyanide	$Co_2[Fe(CN)_6]$	14.74	1.8×10^{-15}
hydrogen phosphate	$CoHPO_4$	6.7	2×10^{-7}
(II) hydroxide	$Co(OH)_2$ fresh	14.23	5.92×10^{-15}
(III) hydroxide	$Co(OH)_3$	43.80	1.6×10^{-44}
iodate	$Co(IO_3)_2$	4.0	1.0×10^{-4}
phosphate	$Co_3(PO_4)_2$	34.69	2.05×10^{-35}
selenite	$CoSeO_3$	6.80	1.6×10^{-7}
quinaldate	CoL_2	10.80	1.6×10^{-11}
8-quinolinolate	CoL_2	24.80	1.6×10^{-25}
sulfide	α-CoS	20.40	4.0×10^{-21}
	β-CoS	24.70	2.0×10^{-25}
Copper(I)			
azide	CuN_3	8.31	4.9×10^{-9}
bromide	CuBr	8.20	6.27×10^{-9}
chloride	CuCl	6.76	1.72×10^{-7}
cyanide	CuCN	19.46	3.47×10^{-20}
hydroxide	CuOH	14	1×10^{-14}
iodide	CuI	11.90	1.27×10^{-12}
sulfide	Cu_2S	47.60	2.5×10^{-48}
tetraphenylborate	CuL	8.0	1.0×10^{-8}
thiocyanate	CuSCN	12.75	1.77×10^{-13}
Copper(II)			
anthranilate	CuL_2	13.22	6.0×10^{-14}
arsenate	$Cu_3(AsO_4)_2$	35.10	7.95×10^{-36}
azide	$Cu(N_3)_2$	9.20	6.3×10^{-10}
carbonate	$CuCO_3$	9.86	1.4×10^{-10}
chromate	$CuCrO_4$	5.44	3.6×10^{-6}
dithiooxamide	CuL	15.12	7.67×10^{-16}
ferrocyanide	$Cu_2[Fe(CN)_6]$	15.89	1.3×10^{-16}
hydroxide	$Cu(OH)_2$	19.66	2.2×10^{-20}
iodate	$Cu(IO_3)_2$	7.16	6.94×10^{-8}
oxalate	CuC_2O_4	9.35	4.43×10^{-10}
phosphate	$Cu_3(PO_4)_2$	36.85	1.40×10^{-37}
pyrophosphate	$Cu_2P_2O_7$	15.08	8.3×10^{-16}
quinaldate	CuL_2	16.80	1.6×10^{-17}
8-quinolinolate	CuL_2	29.70	2.0×10^{-30}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
selenite	$CuSeO_3$	7.68	2.1×10^{-8}
sulfide	CuS	35.20	6.3×10^{-36}
Dysprosium			
chromate 10-water	$Dy_2(CrO_4)_3 \cdot 10H_2O$	8	1×10^{-8}
hydroxide	$Dy(OH)_3$	21.85	1.4×10^{-22}
Erbium			
hydroxide	$Er(OH)_3$	23.39	4.1×10^{-24}
Europium			
hydroxide	$Eu(OH)_3$	23.03	9.38×10^{-24}
Gadolinium			
hydrogen carbonate	$Gd(HCO_3)_3$	1.7	2×10^{-2}
hydroxide	$Gd(OH)_3$	22.74	1.8×10^{-23}
Gallium			
ferrocyanide	$Ga_4[Fe(CN)_6]_3$	33.82	1.5×10^{-34}
hydroxide	$Ga(OH)_3$	35.14	7.28×10^{-36}
8-quinolinolate	GaL_3	40.80	1.6×10^{-41}
Germanium			
oxide	GeO_2	57.0	1.0×10^{-57}
Gold(I)			
chloride	AuCl	12.70	2.0×10^{-13}
iodide	AuI	22.80	1.6×10^{-23}
Gold(III)			
chloride	$AuCl_3$	24.50	3.2×10^{-25}
hydroxide	$Au(OH)_3$	45.26	5.5×10^{-46}
iodide	AuI_3	46	1×10^{-46}
oxalate	$Au_2(C_2O_4)_3$	10	1×10^{-10}
Hafnium			
hydroxide	$Hf(OH)_3$	25.40	4.0×10^{-26}
Holmium			
hydroxide	$Ho(OH)_3$	22.3	5.0×10^{-23}
Indium			
ferrocyanide	$In_4[Fe(CN)_6]_3$	43.72	1.9×10^{-44}
hydroxide	$In(OH)_3$	33.2	6.3×10^{-34}
quinolinolate	InL_3	31.34	4.6×10^{-32}
selenite	$In_2(SeO_3)_3$	32.60	4.0×10^{-33}
sulfide	In_2S_3	73.24	5.7×10^{-74}
Iron(II)			
carbonate	$FeCO_3$	10.50	3.13×10^{-11}
fluoride	FeF_2	5.63	2.36×10^{-6}
hydroxide	$Fe(OH)_2$	16.31	4.87×10^{-17}
oxalate dihydrate	$FeC_2O_4 \cdot 2H_2O$	6.50	3.2×10^{-7}
sulfide	FeS	17.20	6.3×10^{-18}
Iron(III)			
arsenate	$FeAsO_4$	20.24	5.7×10^{-21}
ferrocyanide	$Fe_4[Fe(CN)_6]_3$	40.52	3.3×10^{-41}
hydroxide	$Fe(OH)_3$	38.55	2.79×10^{-39}
phosphate dihydrate	$FePO_4 \cdot 2H_2O$	15.00	9.91×10^{-16}
quinaldate	FeL_3	16.89	1.3×10^{-17}
selenite	$Fe_2(SeO_3)_3$	30.70	2.0×10^{-31}
Lanthanum			
bromate 9-water	$La(BrO_3)_3 \cdot 9H_2O$	2.50	3.2×10^{-3}
fluoride	LaF_3	16.2	7×10^{-17}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
hydroxide	$La(OH)_3$	18.70	2.0×10^{-19}
iodate	$La(IO_3)_3$	11.12	7.50×10^{-12}
molybdate	$La_2(MoO_4)_3$	20.4	4×10^{-21}
oxalate 9-water	$La_2(C_2O_4)_3$	26.60	2.5×10^{-27}
phosphate	$LaPO_4$	22.43	3.7×10^{-23}
sulfide	La_2S_3	12.70	2.0×10^{-13}
tungstate trihydrate	$La_2(WO_4)_3 \cdot 3H_2O$	3.90	1.3×10^{-4}
Lead			
acetate	$Pb(OAc)_2$	2.75	1.8×10^{-3}
anthranilate	PbL_2	9.81	1.6×10^{-10}
arsenate	$Pb_3(AsO_4)_3$	35.39	4.0×10^{-36}
azide	$Pb(N_3)_2$	8.59	2.5×10^{-9}
borate, *meta*	$Pb(BO_2)_3$	10.78	1.6×10^{-11}
bromate	$Pb(BrO_3)_2$	1.70	2.0×10^{-2}
bromide	$PbBr_2$	6.82	6.60×10^{-6}
carbonate	$PbCO_3$	13.13	7.4×10^{-14}
chloride	$PbCl_2$	4.77	1.70×10^{-5}
chloride fluoride	PbClF	8.62	2.4×10^{-9}
chlorite	$Pb(ClO_2)_2$	8.4	4×10^{-9}
chromate	$PbCrO_4$	12.55	2.8×10^{-13}
ferrocyanide	$Pb_2[Fe(CN)_6]$	14.46	3.5×10^{-15}
fluoride	PbF_2	7.48	3.3×10^{-8}
fluoride iodide	PbFI	8.07	8.5×10^{-9}
hydrogen phosphate	$PbHPO_4$	9.90	1.3×10^{-10}
hydrogen phosphite	$PbHPO_3$	6.24	5.8×10^{-7}
hydroxide	$Pb(OH)_2$	14.84	1.43×10^{-15}
hydroxide bromide	PbOHBr	14.70	2.0×10^{-15}
hydroxide chloride	PbOHCl	13.7	2×10^{-14}
hydroxide nitrate	$PbOHNO_3$	3.55	2.8×10^{-4}
iodate	$Pb(IO_3)_2$	12.43	3.69×10^{-13}
iodide	PbI_2	8.01	9.8×10^{-9}
molybdate	$PbMoO_4$	13.00	1.0×10^{-13}
niobate	$Pb(NbO_3)_2$	16.62	2.4×10^{-17}
oxalate	PbC_2O_4	9.32	4.8×10^{-10}
phosphate	$Pb_3(PO_4)_2$	42.10	8.0×10^{-43}
quinaldate	PbL_2	10.60	2.5×10^{-11}
selenate	$PbSeO_4$	6.84	1.37×10^{-7}
selenite	$PbSeO_3$	11.50	3.2×10^{-12}
sulfate	$PbSO_4$	7.60	2.53×10^{-8}
sulfide	PbS	27.10	8.0×10^{-28}
thiocyanate	$Pb(SCN)_2$	4.70	2.0×10^{-5}
thiosulfate	PbS_2O_3	6.40	4.0×10^{-7}
tungstate	$PbWO_4$	6.35	4.5×10^{-7}
Lead(IV)			
hydroxide	$Pb(OH)_4$	65.50	3.2×10^{-66}
Lithium			
carbonate	Li_2CO_3	1.60	2.5×10^{-2}
fluoride	LiF	2.74	1.84×10^{-3}
phosphate	Li_3PO_4	10.63	2.37×10^{-11}
uranylarsenate	$LiUO_2AsO_4$	18.82	1.5×10^{-19}
Lutetium			
hydroxide	$Lu(OH)_3$	23.72	1.9×10^{-24}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
Magnesium			
ammonium phosphate	$MgNH_4PO_4$	12.60	2.5×10^{-13}
arsenate	$Mg_3(AsO_4)_2$	19.68	2.1×10^{-20}
carbonate	$MgCO_3$	5.17	6.82×10^{-6}
carbonate trihydrate	$MgCO_3 \cdot 3H_2O$	5.62	2.38×10^{-6}
fluoride	MgF_2	10.29	5.16×10^{-11}
hydroxide	$Mg(OH)_2$	11.25	5.61×10^{-12}
iodate 4-water	$Mg(IO_3)_2 \cdot 4H_2O$	2.50	3.2×10^{-3}
niobate	$Mg(NbO_3)_2$	16.64	2.3×10^{-17}
oxalate dihydrate	$MgC_2O_4 \cdot 2H_2O$	5.32	4.83×10^{-6}
phosphate	$Mg_3(PO_4)_2$	23.98	1.04×10^{-24}
8-quinolinolate	MgL_2	15.40	4.0×10^{-16}
selenite	$MgSeO_3$	4.89	1.3×10^{-5}
sulfite	$MgSO_3$	2.50	3.2×10^{-3}
Manganese			
anthranilate	MnL_2	6.75	1.8×10^{-3}
arsenate	$Mn_3(AsO_4)_2$	28.72	1.9×10^{-29}
carbonate	$MnCO_3$	10.63	2.34×10^{-11}
ferrocyanide	$Mn_2[Fe(CN)_6]$	12.10	8.0×10^{-13}
iodate	$Mn(IO_3)_2$	6.36	4.37×10^{-7}
hydroxide	$Mn(OH)_2$	12.72	1.9×10^{-13}
oxalate dihydrate	$MnC_2O_4 \cdot 2H_2O$	6.77	1.70×10^{-7}
8-quinolinolate	MnL_2	21.70	2.0×10^{-22}
selenite	$MnSeO_3$	6.90	1.3×10^{-7}
sulfide	MnS amorphous	9.60	2.5×10^{-10}
	MnS crystalline	12.60	2.5×10^{-13}
Mercury(I)			
azide	$Hg_2(N_3)_2$	9.15	7.1×10^{-10}
bromide	Hg_2Br_2	22.19	6.40×10^{-23}
carbonate	Hg_2CO_3	16.44	3.6×10^{-17}
chloride	Hg_2Cl_2	17.84	1.43×10^{-18}
cyanide	$Hg_2(CN)_2$	39.3	5×10^{-40}
chromate	Hg_2CrO_4	8.70	2.0×10^{-9}
ferricyanide	$(Hg_2)_3[Fe(CN)_6]_2$	20.07	8.5×10^{-21}
fluoride	Hg_2F_2	5.51	3.10×10^{-6}
hydrogen phosphate	Hg_2HPO_4	12.40	4.0×10^{-13}
hydroxide	$Hg_2(OH)_2$	23.70	2.0×10^{-24}
iodate	$Hg_2(IO_3)_2$	13.71	2.0×10^{-14}
iodide	Hg_2I_2	28.72	5.2×10^{-29}
oxalate	$Hg_2C_2O_4$	12.76	1.75×10^{-13}
quinaldate	Hg_2L_2	17.90	1.3×10^{-18}
selenite	Hg_2SeO_3	14.20	8.4×10^{-15}
sulfate	Hg_2SO_4	6.19	6.5×10^{-7}
sulfite	Hg_2SO_3	27.0	1.0×10^{-27}
sulfide	Hg_2S	47.0	1.0×10^{-47}
thiocyanate	$Hg_2(SCN)_2$	19.49	3.2×10^{-20}
tungstate	Hg_2WO_4	16.96	1.1×10^{-17}
Mercury(II)			
bromide	$HgBr_2$	19.21	6.2×10^{-20}
hydroxide	$Hg(OH)_2$	25.52	3.2×10^{-26}
iodate	$Hg(IO_3)_2$	12.49	3.2×10^{-13}
iodide	HgI_2	28.54	2.9×10^{-29}
1,10-phenanthroline	HgL_2	24.70	2.0×10^{-25}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
quinaldate	HgL_2	16.80	1.6×10^{-17}
selenite	$HgSeO_3$	13.82	1.5×10^{-14}
sulfide	HgS red	52.4	4×10^{-53}
	HgS black	51.80	1.6×10^{-52}
Neodymium			
carbonate	$Nd_2(CO_3)_3$	32.97	1.08×10^{-33}
hydroxide	$Nd(OH)_3$	21.49	3.2×10^{-22}
Neptunyl(VI)			
hydroxide	$NpO_2(OH)_2$	21.60	2.5×10^{-22}
Nickel			
ammine perrhenate	$[Ni(NH_3)_6][ReO_4]_2$	3.29	5.1×10^{-4}
anthranilate	NiL_2	9.09	8.1×10^{-10}
arsenate	$Ni_3(AsO_4)_2$	25.51	3.1×10^{-26}
carbonate	$NiCO_3$	6.85	1.42×10^{-7}
ferrocyanide	$Ni_2[Fe(CN)_6]$	14.89	1.3×10^{-15}
hydrazine sulfate	$[Ni(N_2H_4)_3]SO_4$	13.15	7.1×10^{-15}
hydroxide	$Ni(OH)_2$ fresh	15.26	5.48×10^{-16}
iodate	$Ni(IO_3)_2$	4.33	4.71×10^{-5}
oxalate	NiC_2O_4	9.4	4×10^{-10}
phosphate	$Ni_3(PO_4)_2$	31.32	4.74×10^{-32}
pyrophosphate	$Ni_2P_2O_7$	12.77	1.7×10^{-13}
quinaldate	NiL_2	10.1	8×10^{-11}
8-quinolinolate	NiL_2	26.1	8×10^{-27}
selenite	$NiSeO_3$	5.0	1.0×10^{-5}
α-sulfide	α-NiS	18.50	3.2×10^{-19}
β-sulfide	β-NiS	24.0	1.0×10^{-24}
γ-sulfide	γ-NiS	25.70	2.0×10^{-26}
Palladium			
(II) hydroxide	$Pd(OH)_2$	31.0	1.0×10^{-31}
(IV) hydroxide	$Pd(OH)_4$	70.20	6.3×10^{-71}
quinaldate	PdL_2	12.90	1.3×10^{-13}
thiocyanate	$Pd(SCN)_2$	22.36	4.39×10^{-23}
Platinum			
(IV) bromide	$PtBr_4$	40.50	3.2×10^{-41}
(II) hydroxide	$Pt(OH)_2$	35	1×10^{-35}
Plutonium			
(III) fluoride	PuF_3	15.60	2.5×10^{-16}
(IV) fluoride	PuF_4	19.20	6.3×10^{-20}
(IV) hydrogen phosphate	$Pu(HPO_4)_2 \cdot xH_2O$	27.7	2×10^{-28}
(III) hydroxide	$Pu(OH)_3$	19.70	2.0×10^{-20}
(IV) hydroxide	$Pu(OH)_4$	55	1×10^{-55}
(IV) iodate	$Pu(IO_3)_4$	12.3	5×10^{-13}
(VI) carbonate	PuO_2CO_3	12.77	1.7×10^{-13}
(V) hydroxide	$PuO_2(OH)$	9.3	5×10^{-10}
(VI) hydroxide	$PuO_2(OH)_2$	24.7	2×10^{-25}
Polonium			
sulfide	PoS	28.26	5.6×10^{-29}
Potassium			
hexabromoplatinate	$K_2[PtBr_6]$	4.20	6.3×10^{-5}
hexachloropalladinate	$K_2[PdCl_6]$	5.22	6.0×10^{-6}
hexachloroplatinate	$K_2[PtCl_6]$	5.13	7.48×10^{-6}
hexafluoroplatinate	$K_2[PtF_6]$	4.54	2.9×10^{-5}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
hexafluorosilicate	$K_2[SiF_6]$	6.06	8.7×10^{-7}
hexafluorozirconate	$K_2[ZrF_6]$	3.3	5×10^{-4}
iodate	KIO_4	3.43	3.74×10^{-4}
perchlorate	$KClO_4$	1.98	1.05×10^{-2}
sodium cobaltinitrite hydrate	$K_2Na[Co(NO_2)_6] \cdot H_2O$	10.66	2.2×10^{-11}
tetraphenylborate	$K[B(C_6H_5)_4]$	7.66	2.2×10^{-8}
uranyl arsenate	$K[UO_2AsO_4]$	22.60	2.5×10^{-23}
uranyl carbonate	$K_4[UO_2(CO_3)_3]$	4.20	6.3×10^{-5}
Praseodymium			
hydroxide	$Pr(OH)_3$	23.45	3.39×10^{-24}
Promethium			
hydroxide	$Pm(OH)_3$	21	1×10^{-21}
Radium			
iodate	$Ra(IO_3)_2$	8.94	1.16×10^{-9}
sulfate	$RaSO_4$	10.44	3.66×10^{-11}
Rhodium			
hydroxide	$Rh(OH)_3$	23	1×10^{-23}
Rubidium			
cobaltinitrite	$Rb_3[Co(NO_2)_6]$	14.83	1.5×10^{-15}
hexachloroplatinate	$Rb_2[PtCl_6]$	7.20	6.3×10^{-8}
hexafluoroplatinate	$Rb_2[PtF_6]$	6.12	7.7×10^{-7}
hexafluorosilicate	$Rb_2[SiF_6]$	6.30	5.0×10^{-7}
perchlorate	$RbClO_4$	2.52	3.0×10^{-3}
periodate	$RbIO_4$	3.26	5.5×10^{-4}
Ruthenium			
hydroxide	$Ru(OH)_3$	36	1×10^{-36}
Samarium			
hydroxide	$Sm(OH)_3$	22.08	8.3×10^{-23}
Scandium			
fluoride	ScF_3	23.24	5.81×10^{-24}
hydroxide	$Sc(OH)_3$	30.65	2.22×10^{-31}
Silver			
acetate	AgOAc	2.71	1.94×10^{-3}
arsenate	Ag_3AsO_4	21.99	1.03×10^{-22}
azide	AgN_3	8.54	2.8×10^{-9}
bromate	$AgBrO_3$	4.27	5.38×10^{-5}
bromide	AgBr	12.27	5.35×10^{-13}
carbonate	Ag_2CO_3	11.07	8.46×10^{-12}
chloride	AgCl	9.75	1.77×10^{-10}
chlorite	$AgClO_2$	3.70	2.0×10^{-4}
chromate	Ag_2CrO_4	11.95	1.12×10^{-12}
cobaltinitrite	$Ag_3[Co(NO_2)_6]$	20.07	8.5×10^{-21}
cyanamide	Ag_2CN_2	10.14	7.2×10^{-11}
cyanate	AgOCN	6.64	2.3×10^{-7}
cyanide	AgCN	16.22	5.97×10^{-17}
dichromate	$Ag_2Cr_2O_7$	6.70	2.0×10^{-7}
dicyanimide	$AgN(CN)_2$	8.85	1.4×10^{-9}
ferrocyanide	$Ag_4[Fe(CN)_6]$	40.81	1.6×10^{-41}
hydroxide	AgOH	7.71	2.0×10^{-8}
hyponitrite	$Ag_2N_2O_2$	18.89	1.3×10^{-19}
iodate	$AgIO_3$	7.50	3.17×10^{-8}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
iodide	AgI	16.07	8.52×10^{-17}
molybdate	Ag_2MoO_4	11.55	2.8×10^{-12}
nitrite	$AgNO_2$	3.22	6.0×10^{-4}
oxalate	$Ag_2C_2O_4$	11.27	5.40×10^{-12}
phosphate	Ag_3PO_4	16.05	8.89×10^{-17}
quinaldate	AgL	16.89	1.3×10^{-17}
perrhenate	$AgReO_4$	4.10	8.0×10^{-5}
selenate	Ag_2SeO_4	7.25	5.7×10^{-8}
selenite	Ag_2SeO_3	15.00	1.0×10^{-15}
selenocyanate	AgSeCN	15.40	4.0×10^{-16}
sulfate	Ag_2SO_4	4.92	1.20×10^{-5}
sulfite	Ag_2SO_3	13.82	1.50×10^{-14}
sulfide	Ag_2S	49.20	6.3×10^{-50}
thiocyanate	AgSCN	11.99	1.03×10^{-12}
vanadate	$AgVO_3$	6.3	5×10^{-7}
tungstate	Ag_2WO_4	11.26	5.5×10^{-12}
Sodium			
ammonium cobaltinitrite	$Na(NH_4)_2[Co(NO_2)_6]$	10.66	2.2×10^{-11}
antimonate	$Na[Sb(OH)_6]$	7.4	4×10^{-8}
hexafluoroaluminate	$Na_2[AlF_6]$	9.39	4.0×10^{-10}
uranyl arsenate	$NaUO_2AsO_4$	21.87	1.3×10^{-22}
Strontium			
arsenate	$Sr_3(AsO_4)_2$	18.37	4.29×10^{-19}
carbonate	$SrCO_3$	9.25	5.60×10^{-10}
chromate	$SrCrO_4$	4.65	2.2×10^{-5}
fluoride	SrF_2	8.36	4.33×10^{-9}
iodate	$Sr(IO_3)_2$	6.94	1.14×10^{-7}
iodate hydrate	$Sr(IO_3)_2 \cdot H_2O$	6.42	3.77×10^{-7}
molybdate	$SrMoO_4$	6.7	2×10^{-7}
niobate	$Sr(NbO_3)_2$	17.38	4.2×10^{-18}
oxalate hydrate	$SrC_2O_4 \cdot H_2O$	6.80	1.6×10^{-7}
phosphate	$Sr_3(PO_4)_2$	27.39	4.0×10^{-28}
8-quinolinolate	SrL_2	9.3	5×10^{-10}
selenate	$SrSeO_4$	3.09	8.1×10^{-4}
selenite	$SrSeO_3$	5.74	1.8×10^{-6}
sulfate	$SrSO_4$	6.46	3.44×10^{-7}
sulfite	$SrSO_3$	7.4	4×10^{-8}
tungstate	$SrWO_4$	9.77	1.7×10^{-10}
Terbium			
hydroxide	$Tb(OH)_3$	21.70	2.0×10^{-22}
Tellurium			
hydroxide	$Te(OH)_4$	53.52	3.0×10^{-54}
Thallium(I)			
azide	TlN_3	3.66	2.2×10^{-4}
bromate	$TlBrO_3$	4.96	1.10×10^{-5}
bromide	TlBr	5.43	3.71×10^{-6}
chloride	TlCl	3.73	1.86×10^{-4}
chromate	Tl_2CrO_4	12.06	8.67×10^{-13}
ferrocyanide dihydrate	$Tl_4[Fe(CN)_6] \cdot 2H_2O$	9.3	5×10^{-10}
hexachloroplatinate	$Tl_2[PtCl_6]$	11.40	4.0×10^{-12}
iodate	$TlIO_3$	5.51	3.12×10^{-6}
iodide	TlI	7.26	5.54×10^{-8}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
oxalate	$Tl_2C_2O_4$	3.7	2×10^{-4}
selenate	Tl_2SeO_4	4.00	1.0×10^{-4}
selenite	Tl_2SeO_3	38.7	2×10^{-39}
sulfide	Tl_2S	20.30	5.0×10^{-21}
thiocyanate	TlSCN	3.80	1.57×10^{-4}
Thallium(III)			
hydroxide	$Tl(OH)_3$	43.77	1.68×10^{-44}
8-quinolinolate	TlL_3	32.40	4.0×10^{-33}
Thorium			
hydrogen phosphate	$Th(HPO_4)_2$	20	1×10^{-20}
hydroxide	$Th(OH)_4$	44.40	4.0×10^{-45}
iodate	$Th(IO_3)_4$	14.60	2.5×10^{-15}
oxalate	$Th(C_2O_4)_2$	22	1×10^{-22}
phosphate	$Th_3(PO_4)_4$	78.60	2.5×10^{-79}
Thullium			
hydroxide	$Tm(OH)_3$	23.48	3.3×10^{-24}
Tin			
(II) hydroxide	$Sn(OH)_2$	27.26	5.45×10^{-28}
(IV) hydroxide	$Sn(OH)_4$	56	1×10^{-56}
(II) sulfide	SnS	25.00	1.0×10^{-25}
Titanium			
(III) hydroxide	$Ti(OH)_3$	40	1×10^{-40}
(IV) oxide hydroxide	$TiO(OH)_2$	29	1×10^{-29}
Uranium(IV)			
fluoride 2.5-water	$UF_4 \cdot 2.5H_2O$	21.24	5.7×10^{-22}
Uranyl(VI)(2+)			
carbonate	UO_2CO_3	11.73	1.8×10^{-12}
ferrocyanide	$UO_2[Fe(CN)_6]$	13.15	7.1×10^{-14}
hydrogen arsenate	UO_2HAsO_4	10.50	3.2×10^{-11}
hydrogen phosphate	UO_2HPO_4	10.67	2.1×10^{-11}
hydroxide	$UO_2(OH)_2$	21.95	1.1×10^{-22}
iodate hydrate	$UO_2(IO_3)_2 \cdot H_2O$	7.50	3.2×10^{-8}
oxalate trihydrate	$UO_2C_2O_4 \cdot 3H_2O$	3.7	2×10^{-4}
phosphate	$(UO_2)_3(PO_4)_2$	46.7	2×10^{-47}
sulfite	UO_2SO_3	8.58	2.6×10^{-9}
thiocyanate	$(UO_2)(SCN)_2$	3.4	4×10^{-4}
Vanadium			
(IV) hydroxide	$VO(OH)_2$	22.13	5.9×10^{-23}
(III) phosphate	$(VO_2)_3PO_4$	24.1	8×10^{-25}
Ytterbium			
hydroxide	$Yt(OH)_3$	23.60	2.5×10^{-24}
Yttrium			
carbonate	$Y_2(CO_3)_3$	2.99	1.03×10^{-3}
fluoride	YF_3	20.06	8.62×10^{-21}
hydroxide	$Y(OH)_3$	22.00	1.00×10^{-22}
iodate	$Y(IO_3)_3$	9.95	1.12×10^{-10}
oxalate	$Y_2(C_2O_4)_3$	28.28	5.3×10^{-29}
Zinc			
anthranilate	ZnL_2	9.23	5.9×10^{-10}
arsenate	$Zn_3(AsO_4)_2$	27.55	2.8×10^{-28}
borate hydrate	$Zn(BO_2)_2 \cdot H_2O$	10.18	6.6×10^{-11}
carbonate	$ZnCO_3$	9.94	1.46×10^{-10}
ferrocyanide	$Zn_2[Fe(CN)_6]$	15.40	4.0×10^{-15}

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	pK_{sp}	K_{sp}
fluoride	ZnF_2	1.52	3.04×10^{-2}
hydroxide	$Zn(OH)_2$	16.5	3×10^{-17}
iodate dihydrate	$Zn(IO_3)_2 \cdot 2H_2O$	5.37	4.1×10^{-6}
oxalate dihydrate	$ZnC_2O_4 \cdot 2H_2O$	8.86	1.38×10^{-9}
phosphate	$Zn_3(PO_4)_2$	32.04	9.0×10^{-33}
quinaldate	ZnL_2	13.80	1.6×10^{-14}
8-quinolinolate	ZnL_2	24.30	5.0×10^{-25}
selenide	ZnSe	25.44	3.6×10^{-26}
selenite hydrate	$ZnSeO_3 \cdot H_2O$	6.80	1.57×10^{-7}
sulfide	α-ZnS	23.80	1.6×10^{-24}
	β-ZnS	21.60	2.5×10^{-22}
Zirconium			
oxide hydroxide	$ZrO(OH)_2$	48.20	6.3×10^{-49}
phosphate	$Zr_3(PO_4)_4$	132	1×10^{-132}

8.2.1 Proton-Transfer Reactions

The pK_a values listed in Tables 8.7 and 8.8 are the negative (decadic) logarithms of the acidic dissociation constant, i.e., $-\log_{10} K_a = pK_a$. For the general proton-transfer reaction

$$HB = H^+ + B$$

the acidic dissociation constant is formulated as follows:

$$K_a = \frac{[H^+][B]}{[HB]}$$

The most common charge types for the acid HB and its conjugate base B are

$$CH_3COOH = H^+ + CH_3COO^- \text{ (acetic acid, acetate ion)}$$

$$HSO_4^- = H^+ + SO_4^{2-} \text{ (hydrogen sulfate ion, sulfate ion)}$$

$$NH_4^+ = H^+ + NH_3 \text{ (ammonium ion, ammonia)}$$

Acids which have more than one acidic hydrogen ionize in steps, as shown for phosphoric acid:

$$H_3PO_4 = H^+ + H_2PO_4^- \qquad pK_1 = 2.148 \qquad K_1 = 7.11 \times 10^{-3}$$

$$H_2PO_4^- = H^+ + HPO_4^{2-} \qquad pK_2 = 7.198 \qquad K_2 = 6.34 \times 10^{-8}$$

$$HPO_4^{2-} = H^+ + PO_4^{3-} \qquad pK_3 = 11.90 \qquad K_3 = 1.26 \times 10^{-12}$$

If the basic dissociation constant K_b for the equilibrium such as

$$NH_3 + H_2O = NH_4^+ + OH^-$$

is required, pK_b may be calculated from the relationship

$$pK_b = pK_w - pK_a$$

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C

Substance	Formula or remarks	pK_1	pK_2
Aluminic acid	H_3AlO_3	11.2	
Aluminum ion (aquo)	Al^{3+} (aquo)	4.98(4)	
Americium(III) ion	Am^{3+} (aquo) $\mu = 0.1$	5.92	
Ammonium ion	NH_4^+	9.246(2)	
Ammonium-d_3	ND_3H^+	9.757	
Antimonic acid	$HSb(OH)_6 = Sb(OH)_6^- + H^+$ $\mu = 0.5$	2.55	
Antimony(III) ion	$SbO^+ + H_2O = Sb(OH)_3 + H^+$ $\mu = 1.0$	1.42	
Barium ion	pK_b of $Ba(OH)^+$ $\mu = 0.1$	0.64	
Berkelium(III) ion	pK for hydrolysis of Bk^{3+} $\mu = 0.1$	5.66	
Beryllium(II) ion	Be^{2+} (aquo) $= BeOH^+ + H^+$ $\mu = 1.0$	6.5	
Bismuth(III) ion	$Bi^{3+} = BiOH^{2+} + H^+$ $\mu = 3.0$	1.58	
Boric acid, tetra-	$H_2B_4O_7$	4	9
Bromine	$Br_2 + H_2O = HBrO + H^+ + Br^-$	7.92	
Cadmium ion	Cd^{2+} (aquo) hydrolysis	9.2(1)	
Calcium ion	Ca^{2+} (aquo) hydrolysis	12.67(3)	
Californium(III) ion	Cf^{3+} (aquo) hydrolysis $\mu = 0.1$	5.62	
Carbon dioxide	CO_2 (aquo)	6.352(1)	10.329
	CO_2 in D_2O	6.77	10.93
Cerium(III) ion	Ce^{3+} (aquo) hydrolysis	*ca.* 9.3	
Cerium(IV) ion	Hydrolysis to $Ce(OH)^{3+}$ and $Ce(OH)_2^{2+}$	−1.15	0.82
Chromium(III) ion	Cr^{3+} (aquo) hydrolysis	3.95	
Cobalt(II) ion	Co^{2+} (aquo) hydrolysis	8.9	
Cobalt(III) ion	Co^{3+} (aquo) hydrolysis $m = 1$	1.75	
Copper(II) ion	Cu^{2+} (aquo) hydrolysis	7.34	
Curium(III) ion	Cm^{3+} (aquo) hydrolysis $m = 0.1$	6.00(5)	
Deuterium oxide	D_2O (molal scale)	14.956(1)	
Dysprosium(III) ion	Dy^{3+} (aquo) hydrolysis	8.10	
Erbium(III) ion	Er^{3+} (aquo) hydrolysis $\mu = 3$	9.0	
Europium(III) ion	Eu^{3+} (aquo) hydrolysis	8.03	
Fermium(III) ion	Fm^{3+} hydrolysis $\mu = 0.1$	3.8	
Gadolinium(III) ion	Gd^{3+} hydrolysis	8.27	
Gallium(III) ion	Ga^{3+} (successive values for hydrolysis)	2.92	3.77
		pK_3 4.75	
Gold(III) hydroxide	H_3AuO_3	<11.7	13.36
Hafnium(IV) ion	Hf^{4+} hydrolysis $\mu = 1$	−0.12	0.23
Hexaminotriphosphazene	$N_3P_3(NH_2)_6$	<3.2	7.68(3)
Holmium(III) ion	Ho^{3+} hydrolysis $\mu = 0.3$	8.04	

Hydrazinium(2+) ion	$^{+}H_3N—NH_3^{+}$	0.27	7.94(3)
Hydrogen amidodisulfonate	$HNSO(OH)_2$	pK_3 8.50	
Hydrogen amidophosphate	$H_2NPO(OH)_2$ (26°C)	2.739	8.102
Hydrogen arsenate	H_3AsO_4	2.223	6.760
Hydrogen-d_3 arsenate	D_3AsO_4	2.596	
Hydrogen arsenite	$HAsO_2$	9.28(10)	
Hydrogen azide	HN_3	4.62	
Hydrogen-*d* azide	DN_3 (in D_2O)	5.115	
Hydrogen borate (3−)	H_3BO_3	9.236	
Hydrogen bromate	$HBrO_3$ (in formamide)	1.02	
Hydrogen bromide	HBr	−8.72(15)	
Hydrogen chlorate	$HClO_3$ (theoretical prediction)	−2.7	
Hydrogen chloride	HCl	−6.2(1)	
Hydrogen-*d* chloride	DCl (in dimethylformamide)	3.58	
Hydrogen chlorite	$HClO_2$	1.94	
Hydrogen chromate	H_2CrO_4	0.74	6.488
Hydrogen cyanate	HOCN	3.46	
Hydrogen cyanide	HCN	9.21	
Hydrogen-*d* cyanide	DCN (in D_2O) $\mu = 0.11$	8.97	
Hydrogen diamidophosphate	$(NH_2)PO(OH)$ (30°C)	1.279(+1)	4.889
Hydrogen diamidothiophosphate	$(NH_2)PO(SH)$ (20°C)	2.0(+1)	4.3
Hydrogen diimidotriphosphate	$(HO)_2PO(NH)PO(OH)(NH)PO(OH)_2$ $\mu = 0.1$	~1	~2
		pK_3 3.03	pK_4 6.61
		pK_5 9.84	
Hydrogen diphosphate	$H_4P_2O_7$	0.91	2.10
		pK_3 6.70	pK_4 9.35
Hydrogen disulfate	$H_2S_2O_7$ (theoretical prediction)	−12	−8
Hydrogen dithionate	$H_2S_2O_6$	−3.4	−0.2
Hydrogen dithionite	$H_2S_2O_4$	0.35	2.45
Hydrogen fluoride	H_2F_2	3.20(4)	
Hydrogen germanate	H_2GeO_4	9.01	12.30
Hydrogen hexafluorosilicate	H_2SiF_6		1.92
Hydrogen hydrosulfite	$H_2S_2O_4$	0.35	2.50
Hydrogen hypobromite	HBrO	8.55	
Hydrogen hypochlorite	HClO	7.537	
Hydrogen hypoiodite	HIO	10.5(5)	
Hydrogen hyponitrite	$H_2N_2O_2$	7.21	11.45(10)
Hydrogen iodate	HIO_3	0.804	

Source: J. J. Christensen, L. D. Hansen, and R. M. Izatt, *Handbook of Proton Ionization Heats and Related Thermodynamic Quantities*, Wiley-Interscience, New York, 1976; D. D. Perrin, *Ionisation Constants of Inorganic Acids and Bases in Aqueous Solution*, 2d ed., Pergamon Press, 1982.

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C (*Continued*)

Substance	Formula or remarks	pK_1	pK_2
Hydrogen-*d* iodate	DIO_3 (in D_2O)	1.15	
Hydrogen iodide	HI	−8.56	
Hydrogen manganate(VI)	H_2MnO_4 (35°C) $\mu = 0.1$		10.15
Hydrogen nitrate	HNO_3	−1.37(7)	
Hydrogen nitrite	HNO_2	3.14(1)	
Hydrogen perchlorate	$HClO_4$	−1.6	
Hydrogen periodate	HIO_4	1.64	
Hydrogen peroxide	H_2O_2	11.64(2)	
Hydrogen peroxophosphate	H_3PO_5 $\mu = 0.2$	1.1	5.5
		pK_3 12.8	
Hydrogen peroxosulfate	H_2SO_5	1.0	9.86
Hydrogen perrhenate	$HReO_4$	−1.25	
Hydrogen pertechnetate	$HTcO_4$	0.3	
Hydrogen perthiocarbonate	H_2CS_4	3.54	7.24
Hydrogen perxenate	H_4XeO_6	pK_3 10.5	
Hydrogen phosphate(3−)	H_3PO_4	2.148(20)	7.198(10)
		pK_3 12.32(6)	
Hydrogen-d_2 phosphate	D_2PO_4 (in D_2O)	7.780	
Hydrogen phosphinate	H_2PHO_2	1.23	
Hydrogen phosphonate	H_2PHO_3	1.43	6.68(14)
Hydrogen selenate	H_2SeO_4		1.66
Hydrogen selenide	H_2Se $\mu = 0.03$	3.89	11.0
Hydrogen selenite	H_2SeO_3	2.62	8.30(15)
Hydrogen silicate(4−)	H_4SiO_4	9.60(10)	11.8(1)
Hydrogen sulfamate	H_2NSO_3H	0.99	
Hydrogen sulfate	H_2SO_4		1.99(1)
Hydrogen sulfide	H_2S	6.97	12.90
Hydrogen sulfite	$SO_2 + H_2O = HSO_3^- = H^+$	1.89	7.205
Hydrogen tellurate	H_6TeO_6	7.65(5)	11.00(5)
Hydrogen telluride	H_2Te (18°C)	2.64	11−12
Hydrogen tellurite	H_2TeO_3 (20°C)	6.27	8.43
Hydrogen tetrafluoroborate	HBF_4	0.5	
Hydrogen tetracyanonickelate	$H_2Ni(CN)_4$	4.69	6.59
Hydrogen tetraperoxochromate	H_3CrO_8 (30°C) $\mu = 3$	7.16	
Hydrogen tetrapolyphosphate	$H_4P_4O_{13}$ $\mu = 0.034$	1.99	2.64
		pK_3 6.62	pK_4 8.2

Hydrogen tetrathiophosphate	H_3PS_4	1.5	3.5
		pK_3 6.6	
Hydrogen thiocyanate	HSCN $\mu = 3$	−1.8	
Hydrogen thiophosphate	H_3PO_3S	1.788	5.427
		pK_3 10.08	
Hydrogen thiosulfate	$H_2S_2O_3$	0.6	1.74
Hydrogen tripolyphosphate	$H_3P_3O_9$	~1	1.7
		pK_3 2.00(10)	
		pK_4 5.83(7)	
		pK_5 8.51(6)	
Hydrogen triselenocarbonate	H_2CSe_3	1.16	7.70
Hydrogen trithiocarbonate	H_2CS_3 (20°C)	2.68	8.18
Hydrogen tungstate	H_2WO_4	2.20	3.70
Hydrogen vanadate(−1)	HVO_3	3.80	
Hydrogen vanadate(3−)	H_3VO_4	3.78	7.78(4)
Hydroxylamine-*N*,*N*-disulfonic acid	$HON(SO_3H)_2$ $\mu = 1.6$	pK_3 11.85	
Hydroxylamine *O*-sulfonate	$^+H_3NOSO_3^-$ $\mu = 1$	1.48	
Imidodiphosphoric acid	$(HO)_2PO(NH)PO(OH)_2$ $\mu = 0.2$	~2	2.85
		pK_3 7.08	pK_4 9.72
Indium(III) ion	In^{3+} hydrolysis	3.54	4.28
Iridium(III) ion	Ir^{3+} hydrolysis $\mu = 1$	4.37	5.20
Iron(II) ion	Fe^{2+} hydrolysis $\mu = 1$	6.8	
Iron(III) ion	Fe^{3+} hydrolysis	2.19	
Lanthanum(III) ion	La^{3+} hydrolysis	9.06	
Lead(II) ion	Pb^{2+} hydrolysis $\mu = 0.3$	7.8	
Lead(IV) ion	Pb^{4+} hydrolysis	1.8	3.2
Lithium(I) ion	Li^+	13.8	
Lutetium(III) ion	Lu^{3+} hydrolysis	7.94	
Magnesium(II) ion	Mg^{2+} hydrolysis	11.41	
Manganese(II) ion	Mn^{2+} hydrolysis	10.59	
Manganese(III) ion	Mn^{3+} hydrolysis	0.4	
Mercury(I) ion	Hg_2^{2+} hydrolysis $\mu = 0.5$	5.0	
Mercury(II) ion	Hg^{2+} hydrolysis $\mu = 0.5$	3.70	2.65
Neodymium(III) ion	Nd^{3+} hydrolysis $\mu = 3$	9.0(5)	
Neptunium(III) ion	Np^{3+} hydrolysis $\mu = 0.3$	7.43	
Neptunium(IV) ion	Np^{4+} hydrolysis $\mu = 2$	2.30	
Neptunium(V) ion	NpO_2^+ hydrolysis	8.90(2)	
Nickel(II) ion	Ni^{2+} hydrolysis	9.86	
Osmium tetroxide	OsO_4 hydrolysis $\mu = 1$	12.1	
Palladium(II) ion	Pd^{2+} (stepwise pK_b values)	13.0	12.8
Pentacyanoaquoferrate(II) ion	$Fe(CN)_5(H_2O)^{3-}$ $\mu = 0.1$	2.63	

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C (*Continued*)

Substance	Formula or remarks	pK_1	pK_2
Plutonium(III) ion	Pu^{3+} hydrolysis $\mu = 0.07$	7.2(2)	
Plutonium(IV) ion	Pu^{4+} hydrolysis $\mu = 2$	1.26	
Plutonium(V) ion	PuO_2^+ hydrolysis $\mu = 0.003$	9.7	
Plutonium(VI) ion	PuO_2^{2+} hydrolysis	3.33	4.05
Polonium(IV) ion	Po^{4+} hydrolysis	0.48	2.74
		pK_3 5.58	
Praseodymium(III) ion	Pr^{3+} hydrolysis $\mu = 0.3$	8.55	
Protoactinium(IV) ion	Pa^{4+} hydrolysis $\mu = 3$	0.14	0.38
Protoactinium(V) ion	Pa^{5+} hydrolysis $\mu = 3$	1.05	
Scandium(III) ion	Sc^{3+} hydrolysis $\mu = 0.05$	4.58(3)	
Silver(I) ion	Ag^+ hydrolysis	>11.1	
Sodium ion	Na^+ (aquo)	14.67(10)	
Strontium ion	Sr^{2+} (aquo)	13.18	
Terbium(III) ion	Tb^{3+} hydrolysis $\mu = 0.3$	8.16	
Thallium(I) ion	Tl^+	13.36(15)	
Thallium(III) ion	Tl^{3+} hydrolysis $\mu = 3$	1.14	
Thorium(IV) ion	Th^{4+} hydrolysis $\mu = 0.5$	3.89	4.20
Tin(II) ion	Sn^{2+} hydrolysis $\mu = 3$	3.81(10)	
Titanium(III)	Ti^{3+} hydrolysis $\mu = 3$	2.55	
Titanium(IV)	$TiO^{2+} + H_2O = TiO(OH)^+ + H^+$	1.3	
Tritium oxide	pK_w for $T_2O = T^+ + OH^-$	15.21	
Uranium(IV) ion	U^{4+} hydrolysis	0.68	
Uranyl(VI) ion	UO_2^{2+} $\mu = 0.035$	5.82	
Vanadium(II) ion	V^{2+} hydrolysis	6.85	
Vanadium(III) ion	V^{3+} hydrolysis	2.92	3.5
Vanadyl(IV) ion	VO^{2+} hydrolysis	6.86(10)	
Vanadyl(V) ion	VO_2^+(20°C) $\mu = 0.1$	1.83	
Xenon trioxide	$XeO_3 + H_2O = HXeO_4^- + H^+$	10.5	
Ytterbium(III) ion	Yb^{3+} hydrolysis	7.99(6)	
Yttrium(III) ion	Y^{3+} hydrolysis $\mu = 0.3$	8.34	
Zinc ion	Zn^{2+} hydrolysis	8.96	
Zirconium(IV) ion	Zr^{4+} hydrolysis $\mu = 1$	-0.32	0.06
		pK_3 0.35	

If a desired organic acid is not entered in Table 8.8, a useful estimate of its pK_a value can sometimes be obtained by making a comparison with recognizably similar compounds for which pK_a values are known: (1) alkyl chains, alicyclic rings, or saturated carbocyclic rings fused to aromatic or heterocyclic rings can be replaced by methyl or ethyl groups; (2) acid-strengthening inductive and mesomeric effects of a nitro group attached to an aromatic ring are very similar to those of a nitrogen atom located at the same position in a heteroaromatic ring (e.g., 3-hydroxypyridine and 3-nitrophenol).

Hammett and Taft substituent constants and, in particular, Tables 9.1 through 9.4 may also prove useful for estimating pK_a values.

8.2.1.1 Calculation of the Approximate pH Value of Solutions

Strong acid: $\mathrm{pH} = -\log\,[\text{acid}]$

Strong base: $\mathrm{pH} = 14.00 + \log\,[\text{base}]$

Weak acid: $\mathrm{pH} = \tfrac{1}{2}pK_a - \tfrac{1}{2}\log\,[\text{acid}]$

Weak base: $\mathrm{pH} = 14.00 - \tfrac{1}{2}pK_b + \tfrac{1}{2}\log\,[\text{base}]$

Salt formed by a weak acid and a strong base:

$$\mathrm{pH} = 7.00 + \tfrac{1}{2}pK_a + \tfrac{1}{2}\log\,[\text{salt}]$$

Acid salts of a dibasic acid:

$$\mathrm{pH} = \tfrac{1}{2}pK_1 + \tfrac{1}{2}pK_2 - \tfrac{1}{2}\log\,[\text{salt}] + \tfrac{1}{2}\log\,(K_1 + [\text{salt}])$$

Buffer solution consisting of a mixture of a weak acid and its salt:

$$\mathrm{pH} = pK_a + \log\left(\frac{[\text{salt}] + [H_3O^+] - [OH^-]}{[\text{acid}] - [H_3O^+] + [OH^-]}\right)$$

8.2.1.2 Calculation of Concentrations of Species Present at a Given pH

$$\alpha_0 = \frac{[H^+]^n}{[H^+]^n + K_1[H^+]^{n-1} + K_1K_2[H^+]^{n-2} + \cdots + K_1K_2\cdots K_n} = \frac{[H_nA]}{C_{\text{acid}}}$$

$$\alpha_1 = \frac{K_1[H^+]^{n-1}}{[H^+]^n + K_1[H^+]^{n-1} + K_1K_2[H^+]^{n-2} + \cdots + K_1K_2\cdots K_n} = \frac{[H_{n-1}A^-]}{C_{\text{acid}}}$$

$$\alpha_2 = \frac{K_1K_2[H^+]^{n-2}}{[H^+]^n + K_1[H^+]^{n-1} + K_1K_2[H^+]^{n-2} + \cdots + K_1K_2\cdots K_n} = \frac{[H_{n-2}A^{2-}]}{C_{\text{acid}}}$$

$$\vdots$$

$$\alpha_n = \frac{K_1K_2\cdots K_n}{[H^+]^n + K_1[H^+]^{n-1} + K_1K_2[H^+]^{n-2} + \cdots + K_1K_2\cdots K_n} = \frac{[A^{n-}]}{C_{\text{acid}}}$$

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C

Ionic strength μ is zero unless otherwise indicated. Protonated cations are designated by (+1), (+ 2), etc., after the pK_a value; neutral species by (0), if not obvious; and negatively charged acids by (−1), (−2), etc.

Substance	pK_1	pK_2	pK_3	pK_4
Abietic acid	7.62			
Acetamide	−0.37(+1)			
Acetamidine	1.60(+1)			
N-(2-Acetamido)-2-aminoethanesulfonic acid (20°C)	6.88			
2-Acetamidobenzoic acid	3.63			
3-Acetamidobenzoic acid	4.07			
4-Acetamidobenzoic acid	4.28			
2-(Acetamido)butanoic acid	3.716			
N-(2-Acetamido)iminodiacetic acid (20°C)	6.62			
3-Acetamidopyridine	4.37(+1)			
Acetanilide	0.4(+1)	13.39(0)$^{40°C}$		
Acetic acid	4.756			
Acetic acid-*d* (in D_2O)	5.32			
Acetoacetic acid (18°C)	3.58			
Acetohydrazine	3.24(+1)			
Acetone oxime	12.2			
2-Acetoxybenzoic acid (acetylsalicyclic acid)	3.48			
3-Acetoxybenzoic acid	4.00			
4-Acetoxybenzoic acid	4.38			
Acetylacetic acid (18°C)	3.58			
N-Acetyl-α-alanine	3.715			
N-Acetyl-β-alanine	4.455			
2-Acetylaminobutanoic acid	3.72			
3-Acetylaminopropionic acid	4.445			
2-Acetylbenzoic acid	4.13			
3-Acetylbenzoic acid	3.83			
4-Acetylbenzoic acid	3.70			
2-Acetylcyclohexanone	14.1			
N-Acetylcysteine (30°C)	9.52			
Acetylenedicarboxylic acid	1.75	4.40		
N-Acetylglycine	3.670			
N-Acetylguanidine	8.23(+1)			
N-α-Acetyl-**L**-histidine	7.08			
Acetylhydroxamic acid (20°C)	9.40			
N-Acetyl-2-mercaptoethylamine	9.92(SH)			
4-Acetyl-β-mercaptoisoleucine (30°C)	10.30			
2-Acetyl-1-naphthol (30°C)	13.40			
N-Acetylpenicillamine (30°C)	9.90			
2-Acetylphenol	9.19			
4-Acetylphenol	8.05			
2-Acetylpyridine	2.643(+1)			
3-Acetylpyridine	3.256(+1)			
4-Acetylpyridine	3.505(+1)			
Aconitine	8.11(+1)			
Acridine	5.60(+1)			
Acrylic acid	4.26			
Adenine	4.17(+1)	9.75(0)		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Adeninedeoxyriboside-5′-phosphoric acid	——	4.4	6.4	
Adenine-*N*-oxide	2.69(+1)	8.49(0)		
Adenosine	3.5(+1)	12.34(0)		
Adenosine-5′-diphosphoric acid	——	4.2(−1)	7.20(−2)	
Adenosine-2′-phosphoric acid	3.81(+1)	6.17(0)		
Adenosine-3′-phosphoric acid	3.65(0)	5.88(−1)		
Adenosine-5′-phosphoric acid	3.74(0)	6.05(−1)	13.06(−2)	
Adenosine-5′-triphosphoric acid	——	4.00(−1)	6.48(−2)	
Adipamic acid (adipic acid monoamide)	4.629			
Adipic acid	4.418	5.412		
α-Alanine	2.34(+1)	9.69(0)		
β-Alanine	3.55(+1)	10.238(0)		
α-Alanine, methyl ester ($\mu = 0.10$)	7.743(+1)			
β-Alanine, methyl ester ($\mu = 0.10$)	9.170(+1)			
N-**D**-Alanyl-α-**D**-alanine ($\mu = 0.1$)	3.32(+1)	8.13(0)		
N-**L**-Alanyl-α-**L**-alanine ($\mu = 0.1$)	3.32(+1)	8.13(0)		
N-**L**-Alanyl-α-**D**-alanine	3.12(+1)	8.30(0)		
N-α-Alanylglycine	3.11(+1)	8.11(0)		
Alanylglycylglycine	3.190(+1)	8.15(0)		
β-Alanylhistidine	2.64	6.86	9.40	
Albumin (bovine serum ($\mu = 0.15$)	10–10.3			
2-Aldoxime pyridine	3.42(+1)	10.22(0)		
Alizarin Black SN	5.79	12.8		
Alizarin-3-sulfonic acid	5.54	11.01		
Allantoin	8.96			
Allothreonine	2.108(+1)	9.096(0)		
Alloxanic acid	6.64			
Allylacetic acid	4.68			
Allylamine	9.69(+1)			
5-Allylbarbituric acid	4.78(+1)			
5-Allyl-5-(-methylbutyl)barbituric acid	8.08			
2-Allylphenol	10.28			
1-Allylpiperidine	9.65(+1)			
2-Allylpropionic acid	4.72			
3-Amidotetrazoline	3.95(+1)			
2-Aminoacetamide	7.95(+1)			
Aminoacetonitrile	5.34(+1)			
9-Aminoacridine (20°C)	9.95(+1)			
4-Aminoantipyrine	4.94(+1)			
2-Aminobenzenesulfonic acid	2.459(0)			
3-Aminobenzenesulfonic acid	3.738(0)			
4-Aminobenzenesulfonic acid	3.227(0)			
2-Aminobenzoic acid	2.09(+1)	4.79(0)		
3-Aminobenzoic acid	3.07(+1)	4.79(0)		
4-Aminobenzoic acid	2.41(+1)	4.85(0)		
2-Aminobenzoic acid, methyl ester	2.36(+1)			
3-Aminobenzoic acid, methyl ester	3.58(+1)			
4-Aminobenzoic acid, methyl ester	2.45(+1)			
3-Aminobenzonitrile	2.75(+1)			
4-Aminobenzonitrile	1.74(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4-Aminobenzophenone	2.15(+1)			
2-Aminobenzothiazole (20°C)	4.48(+1)			
2-Aminobenzoylhydrazide	1.85	3.47	12.80	
2-Aminobiphenyl	3.78(+1)			
3-Aminobiphenyl	4.18(+1)			
4-Aminobiphenyl	4.27(+1)			
4-Amino-3-bromomethylpyridine	7.47(+1)			
4-Amino-3-bromopyridine (20°C)	7.04(+1)			
2-Aminobutanoic acid	2.286(+1)	9.830(0)		
3-Aminobutanoic acid	——	10.14(0)		
4-Aminobutanoic acid	4.031(+1)	10.556(0)		
2-Aminobutanoic acid, methyl ester ($\mu = 0.1$)	7.640(+1)			
4-Aminobutanoic acid, methyl ester ($\mu = 0.1$)	9.838(+1)			
D-(+)-2-Amino-1-butanol	9.52(+1)			
3-Amino-*N*-butyl-3-methyl-2-butanone oxime	9.09(+1)			
4-Aminobutylphosphonic acid	2.55	7.55	10.9	
2-Amino-*N*-carbamoylbutanoic acid	3.886(+1)			
4-Amino-*N*-carbamoylbutanoic acid	4.683(+1)			
2-Amino-*N*-carbamoyl-2-methyl-propanoic acid	4.463			
1-Amino-1-cycloheptanecarboxylic acid	2.59(+1)	10.46(0)		
1-Amino-1-cyclohexanecarboxylic acid	2.65(+1)	10.03(0)		
2-Amino-1-cyclohexanecarboxylic acid	3.56(+1)	10.21(0)		
1-Aminocyclopentane	10.65(+1)			
1-Aminocyclopropane	9.10(+1)			
10-Aminodecylphosphonic acid	——	8.0	11.25	
10-Aminodecylsulfonic acid	2.65(+1)			
1-Amino-2-di(aminomethyl)butane	3.58(+3)	8.59(+2)	9.66(+1)	
2-Amino-*N*,*N*-dihydroxyethyl-2-hydroxyl-1,3-propanediol	6.484(+1)			
2-Amino-*N*,*N*-dimethylbenzoic acid	1.63(+1)	8.42(0)		
4-Amino-2,5-dimethylphenol	5.28(+1)	10.40(0)		
4-Amino-3,5-dimethylpyridine (20°C)	9.54(+1)			
12-Aminododecanoic acid	4.648(+1)			
2-Aminoethane-1-phosphoric acid	5.838	10.64		
1-Aminoethanesulfonic acid	−0.33	9.06		
2-Aminoethanesulfonic acid	1.5	9.061		
2-Aminoethanethiol (cysteamine) ($\mu = 0.01$)	8.23(+1)			
2-Aminoethanol (ethanolamine)	9.50(+1)			
2-[2-(2-Aminoethyl)amino-ethyl]pyridine	3.50	6.59	9.51	
2-Amino-2-ethyl-1-butanol	9.82(+1)			
3-(2-Aminoethyl)indole	——	10.2		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
3-Amino-*N*-ethyl-3-methyl-2-butanone oxime	9.23(+1)			
N-(2-Aminoethyl)morpholine	4.06(+2)	9.15(+1)		
p-(2-Aminoethyl)phenol	9.3	10.9		
2-Aminoethylphosphonic acid	2.45(+1)	7.0(0)	10.8(−1)	
N-(2-Aminoethyl)piperidine (30°C)	6.38	9.89		
2-(2-Aminoethyl)pyridine (μ = 0.5)	4.24(+2)	9.78(+1)		
4-Amino-3-ethylpyridine (20°C)	9.51(+1)			
N-(2-Aminoethyl)pyrrolidine (30°C)	6.56(+2)	9.74(+1)		
2-Aminofluorine	10.34(+1)			
2-Amino-D-β-glucose (μ = 0.05)	2.20(+1)	9.08(0)		
2-Amino-*N*-glycylbutanoic acid	3.155(+1)	8.331(0)		
7-Aminoheptanoic acid	4.502			
2-Aminohexanoic acid	2.335(+1)	9.834(0)		
6-Aminohexanoic acid	4.373(+1)	10.804(0)		
C-Amino-*C*-hydrazinocarbonylmethane	2.38(+2)	7.69(+1)		
2-Amino-3-hydroxybenzoic acid	2.5(+1)	5.192(0)	10.118(OH)	
L-2-Amino-3-hydroxybutanoic acid (threonine)	2.088(+1)	9.100(0)		
DL-2-Amino-4-hydroxybutanoic acid (μ = 0.1)	2.265(+1)	9.257(0)		
DL-4-Amino-3-hydroxybutanoic acid (μ = 0.1)	3.834(+1)	9.487(0)		
2-Amino-2′-hydroxydiethyl sulfide	9.27(+1)			
4-Amino-2-hydroxypyrimidine (cytosine)	4.58(+1)	12.15(0)		
3-Amino-*N*-isopropyl-3-methyl-2-butanone oxime	9.09(+1)			
4-Amino-3-isopropylpyridine (20°C)	9.54(+1)			
1-Aminoisoquinoline (20°C, μ = 0.01)	7.62(+1)			
3-Aminoisoquinoline (20°C, μ = 0.005)	5.05(+1)			
4-Aminoisoxazolidine-3-one	7.4(+1)			
Aminomalonic acid	3.32(+1)	9.83(0)		
DL-2-Amino-4-mercaptobutanoic acid	2.22(+1)	8.87(0)	10.86(SH)	
2-Amino-3-mercapto-3-Methylbutanoic acid	1.8(+1)	7.9(0)	10.5(SH)	
2-Amino-6-methoxybenzothiazole	4.50(+1)			
3-Amino-4-methylbenzenesulfonic acid	3.633			
4-Amino-3-methylbenzenesulfonic acid	3.125			
2-Amino-4-methylbenzothiazole	4.7(+1)			
1-Amino-3-methylbutane	10.64(+1)			
3-Amino-3-methyl-2-butanone oxime	9.09(+1)			
3-Amino-*N*-methyl-3-methyl-2-butanone oxime	9.23(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Amino-3-methylpentanoic acid	2.320(+1)	9.758(0)		
3-Aminomethyl-6-methylpyridine (30°C)	8.70(+1)			
Aminomethylphosphonic acid	2.35	5.9	10.8	
2-Amino-2-methyl-1,3-propanediol	8.801			
2-Amino-2-methyl-1-propanol	9.694(+1)			
2-Amino-2-methylpropanoic acid	2.357(+1)	10.205(0)		
(2-Aminomethyl(pyridine (μ = 0.5)	2.31(+2)	8.79(+1)		
2-Amino-3-methylpyridine	7.24(+1)			
4-Amino-3-methylpyridine	9.43(+1)			
2-Amino-4-methylpyridine	7.48(+1)			
2-Amino-5-methylpyridine	7.22(+1)			
2-Amino-6-methylpyridine	7.41(+1)			
2-Amino-4-methylpyrimidine (20°C)	4.11(+1)			
Aminomethylsulfonic acid	5.57(+1)			
N-Aminomorpholine	4.19(+1)			
4-Amino-1-naphthalenesulfonic acid	2.81			
1-Amino-2-naphthalenesulfonic acid	1.71			
1-Amino-3-naphthalenesulfonic acid	3.20			
1-Amino-5-naphthalenesulfonic acid	3.69			
1-Amino-6-naphthalenesulfonic acid	3.80			
1-Amino-7-naphthalenesulfonic acid	3.66			
1-Amino-8-naphthalenesulfonic acid	5.03			
2-Amino-1-naphthalenesulfonic acid	2.35			
2-Amino-4-naphthalenesulfonic acid	3.79			
2-Amino-6-naphthalenesulfonic acid	3.79	8.94		
2-Amino-8-naphthalenesulfonic acid	3.89			
3-Amino-1-naphthoic acid	2.61	4.39		
4-Amino-2-naphthoic acid	2.89	4.46		
8-Amino-2-naphthol	4.20(+1)			
DL-2-Aminopentanoic acid (**DL**-norvaline)	2.318(+1)	9.808		
3-Aminopentanoic acid	4.02(+1)	10.399(0)		
4-Aminopentanoic acid	3.97(+1)	10.46(0)		
5-Aminopentanoic acid	4.20(+1)	9.758(0)		
5-Aminopentanoic acid, ethyl ester	10.151			
2-Aminophenol	9.28	9.72		
3-Aminophenol	9.83	9.87		
4-Aminophenol	8.50	10.30		
4-Aminophenylacetic acid (20°C)	3.60	5.26		
2-Aminophenylarsonic acid	ca 2	3.77	8.66	

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
3-Aminophenylarsonic acid	ca 2	4.02	8.92	
4-Aminophenylarsonic acid	ca 2	4.02	8.62	
3-Aminophenylboric acid	4.46	8.81		
4-Aminophenylboric acid	3.71	9.17		
4-Aminophenyl (4-chlorophenyl) sulfone	1.38			
2-Aminophenylphosphonic acid	——	4.10	7.29	
3-Aminophenylphosphonic acid	——	——	7.16	
4-Aminophenylphosphonic acid	——	——	7.53	
1-Amino-1,2,3-propanetricarboxylic acid ($\mu = 2.2$)	2.10(+1)	3.60(0)	4.60(−1)	9.82(−2)
3-Aminopropanoic acid	3.551(+1)	10.235(0)		
1-Amino-1-propanol	9.96(+1)			
DL-2-Amino-1-propanol	9.469(+1)			
3-Amino-1-propanol	9.96(+1)			
3-Aminopropene	9.691(+1)			
3-Amino-*N*-propyl-3-methyl-2-butanone oxime	9.09(+1)			
2-Aminopropylsulfonic acid	——	9.15		
2-Aminopyridine	6.71(+1)			
3-Aminopyridine	6.03(+1)			
4-Aminopyridine	9.114(+1)			
2-Aminopyridine-1-oxide	2.58(+1)			
3-Aminopyridine-1-oxide	1.47(+1)			
4-Aminopyridine-1-oxide	3.54(+1)			
8-Aminoquinaldine	4.86(+1)			
2-Aminoquinoline (20°C, $\mu = 0.01$)	7.34(+1)			
3-Aminoquinoline (20°C, $\mu = 0.01$)	4.95(+1)			
4-Aminoquinoline (20°C, $\mu = 0.01$)	9.17(+1)			
5-Aminoquinoline (20°C, $\mu = 0.01$)	5.46(+1)			
6-Aminoquinoline (20°C, $\mu = 0.01$)	5.63(+1)			
8-Aminoquinoline (20°C, $\mu = 0.01$)	3.99(+1)			
4-Aminosalicyclic acid	1.991(+1)	3.917(0)	13.74	
5-Aminosalicyclic acid	2.74(+1)	5.84(0)		
2-Amino-3-sulfopropanoic acid	1.89(+1)	8.70(0)		
4-Amino-2,3,5,6-tetramethylpyridine (20°C)	10.58(+1)			
5-Amino-1,2,3,4-tetrazole (20°C)	1.76	6.07		
2-Aminothiazole (20°C)	5.36(+1)			
1-Amino-3-thiobutane (30°C)	9.18(+1)			
5-Amino-3-thio-1-pentanol (30°C)	9.12(+1)			
2-Aminothiophenol	<2(+1)	7.90(0)		
2-Amino-4,4,4-trifluorobutanoic acid		8.171(0)		
3-Amino-4,4,4-trifluorobutanoic acid		5.831(0)		
3-Amino-2,4,6-trinitroluene		9.5(+1)		
Angiotensin II	10.37			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Anhydroplatynecine	9.40			
Aniline	4.60(+1)			
2-Anilinoethylsulfonic acid	3.80(+1)			
3-Anilinoethylsulfonic acid	4.85(+1)			
Anthracene-1-carboxylic acid	3.68			
Anthracene-2-carboxylic acid	4.18			
Anthracene-9-carboxylic acid	3.65			
Anthraquinone-1-carboxylic acid (20°C)	3.37			
Anthraquinone-2-carboxylic acid (20°C)	3.42			
9,10-Anthraquinone monoxime	9.78			
9,10-Anthraquinone-1-sulfonic acid	0.27			
9,10-Anthraquinone-2-sulfonic acid	0.38			
Antipyrine	1.45(+1)			
Apomorphine (15°C)		8.92		
D-(−)-Arabinose	12.34			
L-(+)-Arginine	2.17	9.04(+1)	12.47(−1)	
Arsenazo III [pK_5 10.5(−4); pK_6 12.0(−5)]		1.2	2.7	7.9(−3)
Arsenoacetic acid		4.67	7.68	
Arsenoacrylic acid		4.23	8.60	
Arsenobutanoic acid		4.92	7.64	
2-Arsenocrotonic acid		4.61	8.75	
3-Arsenocrotonic acid		4.03	8.81	
Arsenopentanoic acid		4.89	7.75	
L-(+)-Ascorbic acid (vitamin C)	4.17	11.57		
L-(+)-Asparagine	2.01(0)	8.80(+1)		
L-Asparaginylglycine		4.53	9.07	
D-Aspartic acid	1.89(0)	3.65	9.60	
Aspartic diamide ($\mu = 0.2$)	7.00			
Aspartylaspartic acid		3.40	4.70	8.26
α-Aspartylhistidine (38°C, $\mu = 0.1$)		3.02	6.82	7.98
β-Aspartylhistidine (38°C, $\mu = 0.1$)		2.95	6.93	8.72
N-Aspartyl-*p*-tyrosine ($\mu = 0.01$)		3.57	8.92	10.23(OH)
Aspidospermine	7.65			
Atropine (17°C)	4.35(+1)			
1-Azacycloheptane	11.11(+1)			
1-Azacyclooctane	11.1(+1)			
Azetidine	11.29(+1)			
Aziridine	8.04(+1)			
Barbituric acid		8.372(0)		
m-Benzbetaine	3.217(+1)			
p-Benzbetaine	3.245(+1)			
Benzenearsonic acid (22°C)		8.48(−1)		
Benzene-1-arsonic acid-4-carboxylic acid		4.22 (COOH)	5.59	
Benzeneboronic acid	13.7			
Benzene-1-carboxylic acid-2-phosphoric acid		3.78	9.17	
Benzene-1-carboxylic acid-3-phosphoric acid		4.03	7.03	

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Benzene-1-carboxylic acid-4-phosphoric acid	1.50	3.95	6.89	
Benzenediazine	11.08(+1)			
1,3-Benzenedicarboxylic acid (isophthalic acid)	3.62(0)	4.60(−1)		
1,4-Benzenedicarboxylic acid (terephthalic acid)	3.54(0)	4.46(−1)		
1,3-Benzenedicarboxylic acid mononitrile	3.60(0)			
1,4-Benzenedicarboxylic acid mononitrile	3.55(0)			
Benzenehexacarboxylic acid (pK_5 6.32; pK_6 7.49)	0.68	2.21	3.52	5.09
Benzenepentacarboxylic acid (pK_5 6.46)	1.80	2.73	3.96	5.25
Benzenesulfinic acid	1.50			
Benzenesulfonic acid	2.554			
1,2,3,4-Benzenetetracarboxylic acid	2.05	3.25	4.73	6.21
1,2,3,5-Benzenetetracarboxylic acid	2.38	3.51	4.44	5.81
1,2,4,5-Benzenetetracarboxylic acid	1.92	2.87	4.49	5.63
1,2,3-Benzenetricarboxylic acid	2.88	4.75	7.13	
1,2,4-Benzenetricarboxylic acid	2.52	3.84	5.20	
1,3,5-Benzenetricarboxylic acid	2.12	4.10	5.18	
Benzil-α-dioxime	12.0			
Benzilic acid	3.09			
Benzimidazole	5.53(+1)	12.3(0)		
Benzohydroxamic acid (20°C)	8.89(0)			
Benzoic acid	4.204			
5,6-Benzoquinoline (20°C)	5.00(+1)			
7,8-Benzoquinoline (20°C)	4.15(+1)			
1,4-Benzoquinone monoxime	6.20			
Benzosulfonic acid	0.70			
1,2,3-Benzotriazole	8.38(+1)			
1-Benzoylacetone	8.23			
Benzoylamine	9.34(+1)			
2-Benzoylbenzoic acid	3.54			
Benzoylglutamic acid	3.49	4.99		
N-Benzoyglycine (hippuric acid)	3.65			
Benzoylhydrazine	3.03(+2)	12.45(+1)		
Benzoylpyruvic acid	6.40	12.10		
3-Benzoyl-1,1,1-trifluoroacetone	6.35			
Benzylamine	9.35(+1)			
Benzylamine-4-carboxylic acid	3.59	9.64		
2-Benzyl-2-phenylsuccinic acid (20°C)	3.69	6.47		
2-Benzylpyridine	5.13(+1)			
4-Benzylpyridine-1-oxide	−1.018(+1)			
1-Benzylpyrrolidine	9.51(+1)			
2-Benzylpyrrolidine	10.31(+1)			
Benzylsuccinic acid (20°C)	4.11	5.65		
3-(Benzylthio)propanoic acid	4.463			
Berberine (18°C)	11.73(+1)			
Betaine	1.832(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Biguanide	2.96(+2)	11.51(+1)		
2,2′-Biimidazolyl (μ = 0.3)	5.01(+1)			
2-Biphenylcarboxylic acid	3.46			
(1,1′-Biphenyl)-4,4′-diamine	3.63(+2)	4.70(+1)		
Bis(2-aminoethyl) ether (30°C)	8.62(+2)	9.59(+1)		
N,*N*′-Bis(2-aminoethyl)-ethylenediamine (20°C)	3.32(+4)	6.67(+3)	9.20(+2)	9.92(+1)
N,*N*-Bis(2-hydroxyethyl)-2-aminoethane sulfonic acid (BES) (20°C)	7.15			
N,*N*-Bis(2-hydroxyethyl)glycine (bicine) (20°C)	8.35			
Bis(2-hydroxyethyl)iminotris (hydroxymethyl)methane (bis-tris)	6.46(+1)			
1,3-Bis[tris(hydroxymethyl)methylamino]propane (20°C)	6.80(+1)			
Bromoacetic acid	2.902			
2-Bromoaniline	2.53(+1)			
3-Bromoaniline	3.53(+1)			
4-Bromoaniline	3.88(+1)			
2-Bromobenzoic acid	2.85			
3-Bromobenzoic acid	3.810			
4-Bromobenzoic acid	3.99			
2-Bromobutanoic acid (35°C)	2.939			
erythro-2-Bromo-3-chlorosuccinic acid (19°C, μ = 0.1)	1.4	2.6		
threo-2-Bromo-chlorosuccinic acid (19°C, μ = 0.1)	1.5	2.8		
trans-2-Bromocinnamic acid	4.41			
3-Bromo-4-(dimethylamino)pyridine (20°C)	6.52(+1)			
2-Bromo-4,6-dinitroaniline	−6.94(+1)			
3-Bromo-2-hydroxymethylbenzoic acid (20°C)	3.28			
6-Bromo-2-hydroxymethylbenzoic acid (20°C)	2.25			
7-Bromo-8-hydroxyquinoline-5-sulfonic acid	2.51	6.70		
3-Bromomandelic acid	3.13			
3-Bromo-4-methylaminopyridine (20°C)	7.49(+1)			
(2-Bromomethyl)butanoic acid	3.92			
Bromomethylphosphonic acid	1.14	6.52		
2-Bromo-6-nitrobenzoic acid	1.37			
2-Bromophenol	8.452			
3-Bromophenol	9.031			
4-Bromophenol	9.34			
2-(2′-Bromophenoxy)acetic acid	3.12			
2-(3′-Bromophenoxy)acetic acid	3.09			
2-(4′-Bromophenoxy)acetic acid	3.13			
2-Bromo-2-phenylacetic acid	2.21			
2-(Bromophenyl) acetic acid	4.054			
4-(Bromophenyl)acetic acid	4.188			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4-Bromophenylarsonic acid	3.25	8.19		
4-Bromophenylphosphinic acid (17°C)	2.1			
2-Bromophenylphosphonic acid	1.64	7.00		
3-Bromophenylphosphonic acid	1.45	6.69		
4-Bromophenylphosphonic acid	1.60	6.83		
3-Bromophenylselenic acid	4.43			
4-Bromophenylselenic acid	4.50			
2-Bromopropanoic acid	2.971			
3-Bromopropanoic acid	3.992			
Bromopropynoic acid	1.855			
2-Bromopyridine	0.71(+1)			
3-Bromopyridine	2.85(+1)			
4-Bromopyridine	3.71(+1)			
3-Bromoquinoline	2.69(+1)			
Bromosuccinic acid	2.55	4.41		
2-Bromo-*p*-tolylphosphonic acid	1.81	7.15		
Brucine (15°C)	2.50(+2)	8.16(+1)		
2-Butanamine (*sec*-butylamine)	10.56(+1)			
1,2-Butanediamine	6.399(+2)	9.388(+1)		
1,4-Butanediamine	9.35(+2)	10.82(+1)		
2,3-Butanediamine	6.91(+2)	10.00(+1)		
1,2,3,4-Butanetetracarboxylic acid	3.43	4.58	5.85	7.16
cis-2-Butenoic acid (isocrotonic acid)	4.44			
trans-2-Butenoic acid (*trans*-crotonic acid) (35°C)	4.676			
3-Butenoic acid (vinylacetic acid)	4.68			
3-Butoxybenzoic acid (20°C)	4.25			
Butylamine	10.64(+1)			
tert-Butylamine	10.685(+1)			
4-*tert*-Butylaniline	3.78(+1)			
N-*tert*-Butylaniline	7.10(+1)			
Butylarsonic acid (18°C)	4.23	8.91		
2-*tert*-Butylbenzoic acid	3.57			
3-*tert*-Butylbenzoic acid	4.199			
4-*tert*-Butylbenzoic acid	4.389			
N-Butylethylenediamine	7.53(+2)	10.30(+1)		
N-Butylglycine	2.35(+1)	10.25(0)		
tert-Butylhydroperoxide	12.80			
1-(*tert*-Butyl)-2-hydroxybenzene	10.62			
1-(*tert*-Butyl)-3-hydroxybenzene	10.119			
1-(*tert*-Butyl)-4-hydroxybenzene	10.23			
Butylmethylamine	10.90(+1)			
2-Butyl-1-methyl-2-pyrroline	11.84(+1)			
4-*tert*-Butylphenylactic acid	4.417			
Butylphosphinic acid	3.41			
tert-Butylphosphinic acid	4.24			
tert-Butylphosphonic acid	2.79	8.88		
1-Butylpiperidine ($\mu = 0.02$)	10.43(+1)			
2-*tert*-Butylpyridine	5.76(+1)			
3-*tert*-Butylpyridine	5.82(+1)			
4-*tert*-Butylpyridine	5.99(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-*tert*-Butylthiazole ($\mu = 0.1$)	3.00(+1)			
4-*tert*-Butylthiazole ($\mu = 0.1$)	3.04(+1)			
2-Butyn-1,4-dioic acid	1.75	4.40		
2-Butynoic acid (tetrolic acid)	2.620			
Butyric acid	4.817			
4-Butyrobetaine (20°C)	3.94(+1)			
Caffeine (40°C)	10.4			
Calcein ($pK_5 > 12$)	<4	5.4	9.0	10.5
Calmagite	8.14	12.35		
D-Camphoric acid	4.57	5.10		
Canaline	2.40	3.70	9.20	
Canavanine	2.50(+2)	6.60(+1)	9.25(0)	
N-Carbamoylacetic acid	3.64			
N-Carbamoyl-α-**D**-alanine	3.89(+1)			
N-Carbamoyl-β-alanine	4.99(+1)			
DL-*N*-Carbamoylalanine	3.892(+1)			
N-Carbamoylglycine	3.876			
2-Carbamoylpyridine (20°C)	2.10(+1)			
3-Carbamoylpyridine	3.328(+1)			
4-Carbamoylpyridine (20°C)	3.61(+1)			
β-Carboxymethylaminopropanoic acid	3.61(+1)	9.46(0)		
Chloroacetic acid	2.867			
N-(2′-Chloroacetyl)glycine	3.38(0)			
cis-3-Chloroacrylic acid (18°C, $\mu = 0.1$)	3.32			
trans-3-chloroacrylic acid (18°C, $\mu = 0.1$)	3.65			
2-Chloroaniline	2.64(+1)			
3-Chloroaniline	3.52(+1)			
4-Chloroaniline	3.99(+1)			
2-Chlorobenzoic acid	2.877			
3-Chlorobenzoic acid	3.83			
4-Chlorobenzoic acid	3.986			
2-Chlorobutanoic acid	2.86			
3-Chlorobutanoic acid	4.05			
4-Chlorobutanoic acid	4.50			
2-Chloro-3-butenoic acid	2.54			
3-Chlorobutylarsonic acid (18°C)	3.95	8.85		
trans-2′-Chlorocinnamic acid	4.234			
trans-3′-Chlorocinnamic acid	4.294			
trans-4′-Chlorocinnamic acid	4.413			
2-Chlorocrotonic acid	3.14			
3-Chlorocrotonic acid	3.84			
Chlorodifluoroacetic acid	0.46			
1-Chloro-1,2-dihydroxybenzene	8.522			
1-Chloro-2,6-dimethyl-4-hydroxybenzene	9.549			
4-Chloro-2,6-dinitrophenol	2.97			
2-Chloroethylarsonic acid	3.68	8.37		
3-Chlorohexyl-1-arsonic acid (18°C)	3.51	8.31		
2-Chloro-3-hydroxybutanoic acid	2.59			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
3-Chloro-2-(hydroxy-methyl)benzoic acid (20°C)	3.27			
6-Chloro-2-(hydroxy-methyl)benzoic acid (20°C)	2.26			
7-Chloro-8-hydroxyquinoline-5-sulfonic acid	2.92	6.80		
2-Chloroisocrotonic acid	2.80			
3-Chloroisocrotonic acid	4.02			
3-Chlorolactic acid	3.12			
3-Chloromandelic acid	3.237			
3-Chloro-4-methoxyphenyl-phosphonic acid	2.25	6.7		
3-Chloro-4-methylaniline	4.05(+1)			
4-Chloro-*N*-methylaniline	3.9(+1)			
4-Chloro-3-methylphenol	9.549			
Chloromethylphosphonic acid	1.40	6.30		
2-Chloro-2-methylpropanoic acid	2.975			
2-Chloro-6-nitroaniline	−2.41(+1)			
4-Chloro-2-nitroaniline	−1.10(+1)			
2-Chloro-3-nitrobenzoic acid	2.02			
2-Chloro-4-nitrobenzoic acid	1.96			
2-Chloro-5-nitrobenzoic acid	2.17			
2-Chloro-6-nitrobenzoic acid	1.342			
4-Chloro-2-nitrophenol	6.48			
2-Chlorophenol	8.55			
3-Chlorophenol	9.10			
4-Chlorophenol	9.43			
(4-Chloro-3-nitrophenoxy)acetic acid	2.959			
2-Chloro-4-nitrophenylphosphonic acid	1.12	6.14		
3-Chloropentyl-1-arsonic acid (18°C)	3.71	8.77		
2-Chlorophenoxyacetic acid	3.05			
3-Chlorophenoxyacetic acid	3.07			
4-Chlorophenoxyacetic acid	3.10			
4-Chlorophenoxy-2-methylacetic acid	3.26			
2-Chlorophenylacetic acid	4.066			
3-Chlorophenylacetic acid	4.140			
4-Chlorophenylacetic acid	4.190			
2-Chlorophenylalanine	2.23(+1)	8.94(0)		
3-Chlorophenylalanine	2.17(+1)	8.91(0)		
DL-4-Chlorophenylalanine	2.08(+1)	8.96(0)		
4-Chlorophenylarsonic acid	3.33	8.25		
2-Chlorophenylphosphonic acid	1.63	6.98		
3-Chlorophenylphosphonic acid	1.55	6.65		
4-Chlorophenylphosphonic acid	1.66	6.75		
3-(2′-Chlorophenyl)propanoic acid	4.577			
3-(3′-Chlorophenyl)propanoic acid	4.585			
3-(4′-Chlorophenyl)propanoic acid	4.607			
3-Chlorophenylselenic acid	4.47			
4-Chlorophenylselenic acid	4.48			
4-Chloro-1,2-phthalic acid	1.60			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Chloropropanoic acid	2.84			
3-Chloropropanoic acid	3.992			
2-Chloropropylarsonic acid (18°C)	3.76	8.39		
3-Chloropropylarsonic acid (18°C)	3.63	8.53		
Chloropropynoic acid	1.854			
2-Chloropyridine	0.49(+1)			
3-Chloropyridine	2.84(+1)			
4-Chloropyridine	3.83(+1)			
7-Chlorotetracycline	3.30(+1)	7.44	9.27	
4-Chloro-2-(2′-thiazolylazo)phenol	7.09			
4-Chlorothiophenol	5.9			
N-Chloro-*p*-toluenesulfonamide	4.54(+1)			
3-Chloro-*o*-toluidine	2.49(+1)			
4-Chloro-*o*-toluidine	3.385(+1)			
5-Chloro-*o*-toluidine	3.85(+1)			
6-Chloro-*o*-toludine	3.62(+1)			
Chrome Azurol S	2.45	4.86	11.47	
Chrome Dark Blue	7.56	9.3	12.4	
Cinchonine	5.85(+2)	9.92(+1)		
cis-Cinnamic acid	3.879			
trans-Cinnamic acid	4.438			
Citraconic acid	2.29(0)	6.15(−1)		
Citric acid	3.128	4.761	6.396	
L-(+)-Citrulline	2.43(+1)	9.41(0)		
Cocaine	8.41(+1)			
Codeine	7.95(+1)			
Colchicine	1.65(+1)			
Coniine ($\mu = 0.5$)	11.24(+1)			
Creatine (40°C)	3.28(+1)			
Creatinine	3.57(+1)			
o-Cresol	10.26			
m-Cresol	10.00			
p-Cresol	10.26			
Cumene hydroperoxide	12.60			
Cupreine	7.63(+1)			
Cyanamide	10.27			
Cyanoacetic acid	2.460			
Cyanoacetohydrazide	2.34(+2)	11.17(+1)		
2-Cyanobenzoic acid	3.14			
3-Cyanobenzoic acid	3.60			
4-Cyanobenzoic acid	3.55			
4-Cyanobutanoic acid	4.44			
trans-1-Cyanocyclohexane-2-carboxylic acid	3.865			
4-Cyano-2,6-dimethylphenol	8.27			
4-Cyano-3,5-dimethylphenol	8.21			
2-Cyanoethylamine	7.7(+1)			
N-(2-Cyano)ethylnorcodeine	5.68(+1)			
Cyanomethylamine	5.34(+1)			
2-Cyano-2-methyl-2-phenylacetic acid	2.290			
1-Cyanomethylpiperidine	4.55(+1)			
2-Cyano-2-methylpropanoic acid	2.422			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
3-Cyanophenol	8.61			
o-Cyanophenoxyacetic acid	2.98			
m-Cyanophenoxyacetic acid	3.03			
p-Cyanophenoxyacetic acid	2.93			
2-Cyanopropanoic acid	2.37			
3-Cyanopropanoic acid	3.99			
2-Cyanopyridine	−0.26(+1)			
3-Cyanopyridine	1.45(+1)			
4-Cyanopyridine	1.90(+1)			
Cyanuric acid	6.78			
Cyclobutanecarboxylic acid	4.785			
1,1-Cyclobutanedicarboxylic acid	3.13	5.88		
cis-1,2-Cyclobutanedicarboxylic acid	3.90	5.89		
trans-1,2-Cyclobutanedicarboxylic acid	3.79	5.61		
cis-1,3-Cyclobutanedicarboxylic acid	4.04	5.31		
trans-1,3-Cyclobutanedicarboxylic acid	3.81	5.28		
Cyclohexanecarboxylic acid	4.90			
1,1-Cyclohexanediacetic acid	3.49	6.96		
cis-1,2-Cyclohexanediacetic acid (20°C)	4.42	5.45		
trans-1,2-Cyclohexanediacetic acid (20°C)	4.38	5.42		
cis-1,2-Cyclohexanediamine	6.43(+2)	9.93(+1)		
trans-1,2-Cyclohexanediamine	6.34(+2)	9.74(+1)		
1,1-Cyclohexanedicarboxylic acid	3.45	4.11		
cis-1,2-Cyclohexanedicarboxylic acid (20°C)	4.34	6.76		
trans-1,2-Cyclohexanedicarboxylic acid (20°C)	4.18	5.93		
cis-1,3-Cyclohexanedicarboxylic acid (16°C)	4.10	5.46		
trans-1,3-Cyclohexanedicarboxylic acid (19°C)	4.31	5.73		
trans-1,4-Cyclohexanedicarboxylic acid (16°C)	4.18	5.42		
1,3-Cyclohexanedione	5.26			
cis,cis-1,3,5-Cyclohexanetriamine	6.9(+3)	8.7(+2)	10.4(+1)	
Cyclohexanonimine	9.15			
cis-4-Cyclohexene-1,2-dicarboxylic acid (20°C)	3.89	6.79		
trans-4-Cyclohexene-1,2-dicarboxylic acid (20°C)	3.95	5.81		
Cyclohexylacetic acid	4.51			
Cyclohexylamine	10.64(+1)			
2-(Cyclohexylamino)ethanesulfonic acid (CHES) (20°C)	9.55			
3-Cyclohexylamino-1-propanesulfonic acid (CAPS) (20°C)	10.40			
4-Cyclohexylbutanoic acid	4.95			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Cyclohexylcyanoacetic acid	2.367			
1,2-Cyclohexylenedinitriloacetic acid ($\mu = 0.1$)	2.4	3.5	6.16	12.35
3-Cyclohexylpropanoic acid	4.91			
2-Cyclohexylpyrrolidine	10.76(+1)			
2-Cyclohexyl-2-pyrroline	7.91(+1)			
Cyclohexylthioacetic acid	3.488			
Cyclopentanecarboxylic acid	4.905			
cis-Cyclopentane-1-carboxylic acid-2-acetic acid	4.40	5.79		
trans-Cyclopentane-1-carboxylic acid-2-acetic acid	4.39	5.67		
Cyclopentane-1,2-diamine-*N*,*N*′,*N*′-tetraacetic acid ($\mu = 0.1$)	——	——	——	10.20
Cyclopentane-1,1-dicarboxylic acid	3.23	4.08		
cis-Cyclopentane-1,2-dicarboxylic acid	4.43	6.67		
trans-Cyclopentane-1,2-dicarboxylic acid	3.96	5.85		
cis-Cyclopentane-1,3-dicarboxylic acid	4.26	5.51		
trans-Cyclopentane-1,3-dicarboxylic acid	4.32	5.42		
Cyclopentylamine	10.65(+1)			
1,1-Cyclopentyldiacetic acid	3.80	6.77		
cis-Cyclopentyl-1,2-diacetic acid	4.42	5.42		
trans-Cyclopentyl-1,2-diacetic acid	4.43	5.43		
Cyclopropanecarboxylic acid	4.827			
Cyclopropane-1,1-dicarboxylic acid	1.82	5.43		
cis-Cyclopropane-1,2-dicarboxylic acid	3.33	6.47		
trans-Cyclopropane-1,2-dicarboxylic acid	3.65	5.13		
Cyclopropylamine	9.10(+1)			
5-Cyclopropyl-1,2,3,4-tetrazole	4.90(+1)			
L-Cysteic acid (3-sulfo-**L**-alanine)	1.89(+1)	8.7(0)		
L-(+)-Cysteine	1.96	8.18	10.29(SH)	
L-(+)-Cysteine, ethyl ester	6.69 (NH_3^+)	9.17(SH)		
L-(+)-Cysteine, methyl ester	6.56 (NH_3^+)	8.99(SH)		
L-Cysteinyl-**L**-asparagine	2.97	7.09	8.47	
L-Cystine (35°C)	1.6(+2)	2.1(+1)	8.02(0)	8.71(−1)
Cystinylglycylglycine (35°C)	3.12	3.21	6.01	6.87
Cytidine	4.08(+1)	12.24(0)		
Cytidine-2′-phosphoric acid	0.8(+1)	4.36(0)	6.17(−1)	
Cytidine-3′-phosphoric acid	0.80(+1)	4.31(0)	6.04(−1)	13.2(sugar)
Cytidine-5′-phosphoric acid	——	4.39(0)	6.62(−1)	
Cytosine	4.58(+1)	12.15(0)		
Decanedioic acid (sebacic acid)	4.59	5.59		
Dehydroascorbic acid (20°C)	3.21	7.92	10.3	
2′-Deoxyadenosine ($\mu = 0.1$)	3.8(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Deoxycholic acid	6.58			
2-Deoxyglucose	12.52			
2-Deoxyguanosine ($\mu = 0.1$)	2.5(+1)			
5-Desoxypyridoxal ($\mu = 0$)	4.17(+1)	8.14(OH)		
1,1-Diacetic acid semicarbazide (30°C, $\mu = 0.1$)	2.96	4.04		
Diacetylacetone	7.42			
Diallylamine ($\mu = 0.02$)	9.29(+1)			
5,5-Diallybarbituric acid	7.78(0)			
1,3-Diamino-2-aminomethylpropane	6.44(+3)	8.56(+2)	10.38(+1)	
3,5-Diaminobenzoic acid	5.30			
1,3-Diamino-*N*,*N*′-bis-(2-aminoethyl)propane ($\mu = 0.5$)	6.01(+4)	7.26(+3)	9.49(+2)	10.23(+1)
2,4-Diaminobutanoic acid (20°C)	1.85(+2)	8.24(+1)	10.40(0)	
2,2′-Diaminodiethyl sulfide (30°C)	8.84(+2)	9.64(+1)		
1,8-Diamino-3,6-dithiooctane (30°C)	8.43(+2)	9.31(+1)		
2,7-Diaminooctanedioic acid (20°C, $\mu = 0.1$)	1.84(+2)	2.64(+1)	9.23(0)	9.89(−1)
1,8-Diamino-3,6-octanedione (30°C)	8.60(+2)	9.57(+1)		
1,8-Diamino-3-oxa-6-thiooctane	8.54(+2)	9.46(+1)		
2,3-Diaminopropanoic acid ($\mu = 0.1$)	1.33(+2)	6.674(+1)	9.623(0)	
2,3-Diaminopropanoic acid, methyl ester ($\mu = 0.1$)	4.412(+1)	8.250(0)		
1,3-Diamino-2-propanol (20°C)	7.93(+2)	9.69(+1)		
2,5-Diaminopyridine (20°C)	2.13(+2)	6.48(+1)		
1,4-Diazabicyclo[2.2.2]octane	2.90(+2)	8.60(+1)		
Dibenzylamine	8.52(+1)			
Dibenzylsuccinic acid (20°C)	3.96	6.66		
Dibromoacetic acid	1.39			
3,5-Dibromoaniline	2.35(+1)			
3,5-Dibromophenol	8.056			
2,2-Dibromopropanoic acid	1.48			
2,3-Dibromopropanoic acid	2.33			
rac-2,3-Dibromosuccinic acid (20°C)	1.43	2.24		
meso-2,3-Dibromosuccinic acid (20°C)	1.51	2.71		
3,5-Dibromo-*p*-L-tyrosine	2.17(+1)	6.45(0)	7.60(−1)	
Dibutylamine	11.25(+1)			
Di-*sec*-butylamine	10.91(+1)			
2,6-Di-*tert*-butylpyridine	3.58(+1)			
rac-2,3-Di-*tert*-butylsuccinic acid ($\mu = 0.1$)	3.58	10.2		
1,12-Dicarboxydodecaborane	9.07	10.23		
Dichloroacetic acid	1.26			
Dichloroacetylacetic acid	2.11			
3,5-Dichloroaniline	2.37(+1)			
1,3-Dichloro-2,5-dihydroxybenzene ($\mu = 0.65$)	7.30	9.99		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2,5-Dichloro-3,6-dihydroxy-*p*-benzoquinone	1.09	2.42		
Dichloromethylphosphonic acid	1.14	5.61		
2,4-Dichloro-6-nitroaniline	−3.00(+1)			
2,5-Dichloro-4-nitroaniline	−1.74(+1)			
2,6-Dichloro-4-nitroaniline	−3.31(+1)			
2,3-Dichlorophenol	7.44			
2,4-Dichlorophenol	7.85			
2,6-Dichlorophenol	6.78			
3,4-Dichlorophenol	8.630			
3,5-Dichlorophenol	8.179			
2,4-Dichlorophenoxyacetic acid (2,4-D)	2.64			
4,6-Dichlorophenoxy-2-methylacetic acid	3.13			
3,6-Dichlorophthalic acid	1.46			
2,2-Dichloropropanoic acid	2.06			
2,3-Dichloropropanoic acid	2.85			
rac-2,3-Dichlorosuccinic acid (20°C)	1.43	2.81		
meso-2,3-Dichlorosuccinic acid	1.49	2.97		
3,5-Dichloro-*p*-tyrosine	2.12	6.47	7.62	
2-Dicyanoethylamine	5.14(+1)			
2,2-Dicyanopropanoic acid	−2.8			
Dicyclohexylamine	11.25(+1)			
Dicyclopentylamine	10.93(+1)			
Didodecylamine	10.99(+1)			
Diethanolamine	8.88(+1)			
Di(ethoxyethyl)amine	8.47(+1)			
3,5-Diethoxyphenol	9.370			
3-(Diethoxyphosphinyl)benzoic acid	3.65			
4-(Diethoxyphosphinyl)benzoic acid	3.60			
3-(Diethoxyphosphinyl)phenol	8.66			
4-(Diethoxyphosphinyl)phenol	8.28			
Diethylamine	10.8(+1)			
2-(Diethylamino)ethyl-4-aminobenzoate	8.85(+1)			
α-(Diethylamino)toluene	9.44(+1)			
N,*N*-Diethylaniline	6.56(+1)			
5,5-Diethylbarbituric acid (veronal)	8.020(0)			
N,*N*-Diethylbenzylamine	9.48(+1)			
Diethylbiguanide (30°C)	2.53(+1)	11.68(0)		
Diethylenetriamine	4.42(+3)	9.21(+2)	10.02(+1)	
Diethylenetriaminepentaacetic acid (pK_5, 10.58)	1.80(0)	2.55(−1)	4.33(−2)	8.60(−3)
N,*N*-Diethylethylenediamine	7.70(+2)	10.46(+1)		
2,2-Diethylglutaric acid	3.62	7.12		
N,*N*-Diethylglycine	2.04(+1)	10.47(0)		
Diethylglycolic acid (18°C)	3.804			
Diethylmalonic acid	2.151	7.417		
Diethylmethylamine	10.43(+1)			
rac-2,3-Diethylsuccinic acid	3.63	6.46		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
meso-2,3-Diethylsuccinic acid	3.54	6.59		
N,*N*-Diethyl-*o*-toluidine	7.18(+1)			
Difluoroacetic acid	1.33			
3,3-Difluoroacrylic acid	3.17			
Diglycolic acid	2.96			
Diguanidine	12.8			
Dihexylamine	11.0(+1)			
Dihydroarecaidine	9.70			
Dihydroarecaidine, methyl ester	8.39			
Dihydrocodeine	8.75(+1)			
Dihydroergonovine	7.38(+1)			
α-Dihydrolysergic acid	3.57	8.45		
γ-Dihydrolysergic acid	3.60	8.71		
α-Dihydrolysergol	8.30			
β-Dihydrolysergol	8.23			
Dihydromorphine	9.35			
3,4-Dihydroxyalanine	2.32(+1)	8.68(0)	9.87(−1)	
1,2-Dihydroxyanthraquinone-3-sulfonic acid (alizarin-3-sulfonic acid)	——	5.54(−1)	11.01(−2)	
3,4-Dihydroxybenzaldehyde	7.55			
1,2-Dihydroxybenzene (pyrocatechol) (μ = 0.1)	9.356(0)	12.98(−1)		
1,3-Dihydroxybenzene (resorcinol)	9.44(0)	12.32(−1)		
1,4-Dihydroxybenzene (hydroquinone)	9.91(0)	12.04(−1)		
4,5-Dihydroxybenzene-1,3-disulfonic acid	——	——	7.66(−2)	12.6(−3)
2,3-Dihydroxybenzoic acid (30°C)	2.98	10.14		
2,4-Dihydroxybenzoic acid (β-resorcylic acid)	3.29	8.98		
2,5-Dihydroxybenzoic acid	2.97	10.50		
2,6-Dihydroxybenzoic acid	1.30			
3,4-Dihydroxybenzoic acid	4.48	8.67	11.74	
3,5-Dihydroxybenzoic acid	4.04			
2,5-Dihydroxy-*p*-benzoquinone	2.71	5.18		
3,4-Dihydroxy-3-cyclobutene-1,2-dione	0.541	3.480		
2,3-Dihydroxy-2-cyclopenten-1-one (20°C)	4.72			
1,4-Dihydroxy-2,6-dinitrobenzene	4.42	9.14		
Di(2,2′-hydroxyethyl)amine	8.8(+1)			
N,*N*-Di(2-hydroxyethyl)glycine	8.333			
Dihydroxymaleic acid	1.10			
Dihydroxymalic acid	1.92			
1,3-Dihydroxy-2-methylbenzene (μ = 0.65)	10.05	11.64		
2,2-Di(hydroxymethyl)-3-hydroxypropanoic acid	4.460			
2,4-Dihydroxy-5-methylpyrimidine	9.90			
2,4-Dihydroxy-6-methylpyrimidine	9.52			
1,4-Dihydroxynaphthalene (26°C, μ = 0.65)	9.37	10.93		
1,2-Dihydroxy-3-nitrobenzene	6.68			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
1,2-Dihydroxy-4-nitrobenzene ($\mu = 0.1$)	6.701			
2,4-Dihydroxy-1-phenylazobenzene ($\mu = 0.1$)	11.98			
2,4-Dihydroxyoxazolidine	6.11(+1)			
2,4-Dihydroxypteridine	<1.3	7.92		
2,6-Dihydroxypurine	7.53(0)	11.84(−1)		
2,4-Dihydroxypyridine (20°C)	1.37(+1)	6.45(0)	13(−1)	
Dihydroxytartaric acid	1.95	4.00		
1,4-Dihydroxy-2,3,5,6-tetramethylbenzene ($\mu = 0.65$)	11.25	12.70		
3,5-Diiodoaniline	2.37(+1)			
2,5-Diiodohistamine	2.31(+2)	8.20(+1)	10.11(0)	
2,5-Diiodohistidine ($\mu = 0.1$)	2.72	8.18	9.76	
3,5-Diiodophenol	8.103			
3,5-Diiodotyrosine	2.117(+1)	6.479(0)	7.821(−1)	
Diisopropylmalonic acid	2.124	8.848		
Dilactic acid	2.955			
threo-1,4-Dimercapto-2,3-butanediol	8.9			
meso-2,3-Dimercaptosuccinic acid	2.71	3.48	8.89(SH)	10.79(SH)
3,5-Dimethoxyaniline	3.86(+1)			
2,6-Dimethoxybenzoic acid	3.44			
1,10-Dimethoxy-3,8-dimethyl-4,7-phenanthroline	7.21			
Di(2-methoxyethyl)amine	9.51(+1)			
3,5-Dimethoxyphenol	9.345			
(3,4-Dimethoxy)phenylacetic acid	4.333			
Dimethylamine	10.77(+1)			
4-Dimethylaminobenzaldehyde	1.647(+1)			
N,*N*-Dimethylaminocyclohexane	10.72(+1)			
4-Dimethylamino-2,3-dimethyl-1-phenyl-3-pyrazolin-5-one	4.18(+1)			
4-Dimethylamino-3,5-dimethylpyridine (20°C)	8.15(+1)			
2-(Dimethylamino)ethanol	9.26(+1)			
2-[2-(Dimethylamino)ethyl]pyridine	3.46(+2)	8.75(+1)		
3-(Dimethylaminoethyl)pyridine	4.30(+2)	8.86(+1)		
4-(Dimethylaminoethyl)pyridine	4.66(+2)	8.70(+1)		
4-(Dimethylamino)-3-ethylpyridine (20°C)	8.66(+1)			
4-(Dimethylamino)-3-isopropylpyridine (20°C)	8.27(+1)			
2-(Dimethylaminomethyl)pyridine	2.58(+2)	8.12(+1)		
3-(Dimethylaminomethyl)pyridine	3.17(+2)	8.00(+1)		
4-(Dimethylaminomethyl)pyridine	3.39(+2)	7.66(+1)		
4-(Dimethylamino)-3-methylpyridine (20°C)	8.68(+1)			
4-(Dimethylaminophenyl)phosphonic acid	2.0(+1)	4.2	7.35	
3-(Dimethylamino)propanoic acid	9.85(+1)			
4-(Dimethylamino)pyridine (20°C)	6.09(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
N,*N*-Dimethylaniline	5.15(+1)			
2,3-Dimethylaniline	4.70(+1)			
2,4-Dimethylaniline	4.89(+1)			
2,5-Dimethylaniline	4.53(+1)			
2,6-Dimethylaniline	3.95(+1)			
3,4-Dimethylaniline	5.17(+1)			
3,5-Dimethylaniline	4.765(+1)			
N,*N*-Dimethylaniline-4-phosphonic acid (17°C)	2.0(+1)	4.2	7.39	
Dimethylarsinic acid (cacodylic acid)	1.67	6.273		
1,3-Dimethylbarbituric acid	4.68(+1)			
2,3-Dimethylbenzoic acid	3.771			
2,4-Dimethylbenzoic acid	4.217			
2,5-Dimethylbenzoic acid	3.990			
2,6-Dimethylbenzoic acid	3.362			
3,4-Dimethylbenzoic	4.41			
3,5-Dimethylbenzoic acid	4.302			
N,*N*-Dimethylbenzylamine	9.02(+1)			
Dimethylbiguanide	2.77(+1)	11.52		
2,2-Dimethylbutanoic acid (18°C)	5.03			
Dimethylchlorotetracycline (μ = 0.01)	3.30(+1)			
2,6-Dimethyl-4-cyanophenol	8.27			
3,5-Dimethyl-4-cyanophenol	8.21			
5,5-Dimethyl-1,3-cyclohexanedione	5.15			
cis-3,3-Dimethyl-1,2-cyclopropane-dicarboxylic acid	2.34	8.31		
trans-3,3-Dimethyl-1,2-cyclopropanedicarboxylic acid	3.92	5.32		
3,5-Dimethyl-4-(dimethylamino)-pyridine (20°C)	8.12(+1)			
2,2-Dimethyl-1,3-dioxane-4,6-dione	5.1			
1,1-Dimethylethanethiol (μ = 0.1)	11.22			
N,*N*-Dimethylethylenediamine-*N*,*N*-diacetic acid	6.63	9.53		
N,*N*′-Dimethylethylenediamine-*N*,*N*′-diacetic acid	7.40	10.16		
N,*N*-Dimethylethylenediamine-*N*,*N*′-diacetic acid	5.99	9.97		
N,*N*-Dimethylglycine	2.146(+1)	9.940(0)		
Dimethylglycolic acid (18°C)	4.04			
N,*N*-Dimethylglycylglycine	3.11(+1)	8.09(0)		
Dimethylglyoxime	10.60			
5,5-Dimethyl-2,4-hexanedione	10.01			
5,5-Dimethylhydantoin	9.19			
2,4-Dimethyl-8-hydroxyquinoline	6.20(+1)	10.60(0)		
3,4-Dimethyl-8-hydroxyquinoline	5.80(+1)	10.05(0)		
2,4-Dimethyl-8-hydroxyquinoline-7-sulfonic acid	3.20 (NH^+)	10.14(OH)		
Dimethylhydroxytetracycline	7.5	9.4		
2,4-Dimethylimidazole	8.38(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Dimethylmalic acid	3.17	6.06		
2,2-Dimethylmalonic acid	3.17	6.06		
3,5-Dimethyl-4-(methylamino) pyridine (20°C)	9.96(+1)			
2,3-Dimethylnaphthalene-1-carboxylic acid	3.33			
2,6-Dimethyl-4-nitrophenol	7.190			
3,5-Dimethyl-4-nitrophenol	8.245			
α,α-Dimethyloxaloacetic acid	1.77	4.62		
3,3-Dimethylpentanedioic acid	3.70	6.34		
2,2-Dimethylpentanoic acid	4.969			
4,4-Dimethylpentanoic acid (18°C)	4.79			
2,3-Dimethylphenol	10.50			
2,4-Dimethylphenol	10.58			
2,5-Dimethylphenol	10.22			
2,6-Dimethylphenol	10.59			
3,4-Dimethylphenol	10.32			
3,5-Dimethylphenol	10.15			
2,6-Dimethylphenoxyacetic acid	3.356			
Dimethylphenylsilylacetic acid	5.27			
N,*N*′-Dimethylpiperazine	4.630(+2)	8.539(+1)		
1,2-Dimethylpiperidine	10.22			
cis-2,6-Dimethylpiperidine	11.07(+1)			
2,2-Dimethylpropanoic acid (pivalic acid)	5.031			
2,2′-Dimethylpropylphosphonic acid	2.84	8.65		
2,4-Dimethylpyridine (2,4-lutidine)	6.74(+1)			
2,5-Dimethylpyridine (2,5-lutidine)	6.43(+1)			
2,6-Dimethylpyridine (2,6-lutidine)	6.71(+1)			
3,4-Dimethylpyridine (3,4-lutidine)	6.47(+1)			
3,5-Dimethylpyridine (3,5-lutidine)	6.09(+1)			
2,4-Dimethylpyridine-1-oxide	1.627(+1)			
2,5-Dimethylpyridine-1-oxide	1.208(+1)			
2,6-Dimethylpyridine-1-oxide	1.366(+1)			
3,4-Dimethylpyridine-1-oxide	1.493(+1)			
3,5-Dimethylpyridine-1-oxide	1.181(+1)			
2,3-Dimethylquinoline	4.94(+1)			
2,6-Dimethylquinoline	5.46(+1)			
meso-2,2-Dimethylsuccinic acid	3.77	5.936		
rac-2,2-Dimethylsuccinic acid	3.93	6.20		
D-2,3-Dimethylsuccinic acid	3.82	5.93		
meso-2,3-Dimethylsuccinic acid	3.67	5.30		
rac-2,3-Dimethylsuccinic acid	3.94	6.20		
2,4-Dimethylthiazole ($\mu = 0.1$)	3.98			
2,5-Dimethylthiazole ($\mu = 0.1$)	3.91			
4,5-Dimethylthiazole ($\mu = 0.1$)	3.73			
N,*N*-Dimethyl-*o*-toluidine	5.86(+1)			
N,*N*-Dimethyl-*p*-toluidine	7.24(+1)			
2,4-Dinitroaniline	−4.25(+1)			
2,6-Dinitroaniline	−5.23(+1)			
3,5-Dinitroaniline	0.229(+1)			
2,3-Dinitrobenzoic acid	1.85			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2,4-Dinitrobenzoic acid	1.43			
2,5-Dinitrobenzoic acid	1.62			
2,6-Dinitrobenzoic acid	1.14			
3,4-Dinitrobenzoic acid	2.82			
3,5-Dinitrobenzoic acid	2.85			
1,1-Dinitrobutane (20°C)	5.90			
1,1-Dinitrodecane	3.60			
1,1-Dinitroethane (20°C)	5.21			
Dinitromethane (20°C)	3.60			
1,1-Dinitropentane	5.337			
2,4-Dinitrophenol	4.08			
2,5-Dinitrophenol	5.216			
2,6-Dinitrophenol	3.713			
3,4-Dinitrophenol	5.424			
3,5-Dinitrophenol	6.732			
2,4-Dinitrophenylacetic acid	3.50			
1,1-Dinitropropane (20°C)	5.5			
2,6-Dioxo-1,2,3,6-tetrahydro-4-pyrimidinecarboxylic acid (orotic acid)	1.8(+1)	9.55(0)		
Diphenylacetic acid	3.939			
Diphenylamine	0.9(+1)			
2,2-Diphenylglutaric acid (20°C)	3.91	5.38		
1,3-Diphenylguanidine	10.12			
2,2-Diphenylheptanedioic acid (20°C)	4.28	5.39		
2,2-Diphenylhexanedioic acid (20°C)	4.17	5.40		
3,3-Diphenylhexanedioic acid	4.22	5.19		
Diphenylhydroxyacetic acid (35°C)	3.05			
Diphenylketimine	6.82			
2,2-Diphenylnonanedioic acid (20°C)	4.33	5.38		
meso-2,2-Diphenylsuccinic acid	3.48			
rac-2,2-Diphenylsuccinic acid	3.58			
2,2-Diphenylsuccinic acid, 1-methyl ester (20°C)	4.47			
2,2-Diphenylsuccinic acid, 4-methyl ester (20°C)	3.900			
Diphenylthiocarbazone	4.50	15		
Dipropylamine	10.91(+1)			
Dipropylenetriamine	7.72(+3)	9.56(+2)	10.65(+1)	
2,2-Dipropylglutaric acid	3.688	7.31		
Dipropylmalonic acid	2.04	7.51		
2,2′-Dipyridyl	−0.52(+2)	4.352(+1)		
2,3′-Dipyridyl (20°C)	1.52(+2)	4.42(+1)		
2,4′-Dipyridyl (20°C)	1.19(+2)	4.77(+1)		
3,3′-Dipyridyl (20°C, $\mu = 0.2$)	3.0(+2)	4.60(+1)		
3.4′-Dipyridyl (20°C, $\mu = 0.2$)	3.0(+2)	4.85(+1)		
4,4′-Dipyridyl	3.17(+2)	4.82(+1)		
Dithiodiacetic acid (18°C)	3.075	4.201		
1,4-Dithioerythritol	9.5			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Dithiooxamide (rubeanic acid)	10.89			
Dulcitol	13.46			
Ecgonine	10.91			
Emetine	7.36(+1)	8.23(0)		
Epinephrine enantiomorph	9.39(+1)			
Epinephrine, pseudo	9.53(+1)			
Ergometrinine	7.32(+1)			
Ergonovine	6.73(+1)			
Eriochrome Black T	6.3	11.55		
1,2-Ethanediamine	6.85(+2)	9.92(+1)		
Ethane-1,2-diamino-*N*,*N*′-dimethyl-*N*,*N*′-diacetic acid (20°C)	6.047(0)	10.068(−1)		
1,2-Ethanedithiol	8.96	10.54		
Ethanethiol ($\mu = 0.015$)	10.61			
Ethoxyacetic acid (18°C)	3.65			
2-Ethoxyaniline (*o*-phenetidine)	4.47(+1)			
3-Ethoxyaniline	4.17(+1)			
4-Ethoxyaniline	5.25(+1)			
2-Ethoxybenzoic acid (20°C)	4.21			
3-Ethoxybenzoic acid (20°C)	4.17			
4-Ethoxybenzoic acid (20°C)	4.80			
Ethoxycarbonylethylamine	9.13(+1)			
2-Ethoxyethanethiol	9.38			
2-Ethoxyethylamine	6.26(+1)			
2-Ethoxyphenol	10.109			
3-Ethoxyphenol	9.655			
(4-Ethoxyphenyl)phosphonic acid	2.06	7.28		
4-Ethoxypyridine	6.67(+1)			
Ethyl acetoacetate	10.68			
3-Ethylacrylic acid	4.695			
N-Ethylalanine	2.22(+1)	10.22(0)		
Ethylamine	10.63(+1)			
(3-Ethylamino)phenylphosphonic acid	1.1(+1)	4.90(0)	7.24(−1)	
N-Ethylaniline	5.11(+1)			
2-Ethylaniline	4.42(+1)			
3-Ethylaniline	4.70(+1)			
4-Ethylaniline	5.00(+1)			
Ethylarsonic acid (18°C)	3.89	8.35		
Ethylbarbituric acid	3.69(+1)			
2-Ethylbenzimidazole ($\mu = 0.16$)	6.27(+1)			
2-Ethylbenzoic acid	3.79			
4-Ethylbenzoic acid	4.35			
Ethylbiguanide	2.09(+1)	11.47(0)		
2-Ethylbutanoic acid (20°C)	4.710			
S-Ethyl-L-cysteine ($\mu = 0.1$)	2.03(+1)	8.60(0)		
Ethylenebiguanide (30°C)	1.74	2.88	11.34	11.76
Ethylenebis(thioacetic acid) (18°C)	3.382(0)	4.352(−1)		
Ethylenediamine-*N*,*N*′-diacetic acid	6.42	9.46		
Ethylenediamine-*N*,*N*-dimethyl-*N*′,*N*′-diacetic acid	6.047	10.068		
Ethylenediamine-*N*,*N*-dipropanoic acid (30°C)	6.87	9.60		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Ethylenediamine-*N*,*N*,*N*′,*N*′-tetra-acetic acid ($\mu = 0.1$)	1.99	2.67	6.16	10.26
Ethylenediamine-*N*,*N*,*N*′,*N*′-tetra-propanoic acid (30°C)	3.00	3.43	6.77	9.60
Ethylene glycol	14.22			
Ethyleneimine	8.04(+1)			
cis-Ethylene oxide dicarboxylic acid	1.93	3.92		
trans-Ethylene oxide dicarboxylic acid	1.93	3.25		
N-Ethylethylenediamine	7.63(+2)	10.56(+1)		
N-Ethylglycine ($\mu = 0.1$)	2.34(+1)	10.23(0)		
3-Ethylglutaric acid	4.28	5.33		
Ethyl hydroperoxide	11.80			
Ethyl hydrogen malonate	3.55			
3-Ethyl-2-hydroxypyridine	5.00(+1)			
Ethylmalonic acid	2.90(0)	5.55(−1)		
N-Ethyl mercaptoacetamide	8.14(SH)			
Ethyl 2-mercaptoacetate	7.95(SH)			
Ethyl 3-mercaptopropanoate	9.48(SH)			
3-Ethyl-4-(methylamino)pyridine (20°C)	9.90(+1)			
5-Ethyl-5-(1-methylbutyl)barbituric acid	8.11(0)			
Ethyl methyl ketoxime	12.45			
Ethylmethylmalonic acid	2.86(0)	6.41(−1)		
1-Ethyl-2-methylpiperidine	10.66(+1)			
3-Ethyl-6-methylpyridine (20°C)	6.51(+1)			
3-Ethyl-4-methylpyridine-1-oxide	−1.534(+1)			
5-Ethyl-2-methylpyridine-1-oxide	−1.288(+1)			
1-Ethyl-2-methyl-2-pyrroline	11.84(+1)			
Ethylmorphine (15°C)	8.08			
Ethyl nitroacetate	5.85			
3-Ethylpentane-2,4-dione	11.34			
2-Ethylpentanoic acid (18°C)	4.71			
5-Ethyl-5-pentylbarbituric acid	7.960			
2-Ethylphenol	10.2			
3-Ethylphenol	10.07			
4-Ethylphenol	10.0			
4-Ethylphenylacetic acid	4.373			
5-Ethyl-5-phenylbarbituric acid	7.445			
Ethylphosphinic acid	3.29			
Ethylphosphonic acid	2.43	8.05		
1-Ethylpiperidine ($\mu = 0.01$)	10.45(+1)			
2,2-Ethylpropylglutaric acid	3.511			
Ethylpropylmalonic acid	3.14	7.43		
2-Ethylpyridine	5.89(+1)			
3-Ethylpyridine (20°C)	5.80(+1)			
4-Ethylpyridine	5.87(+1)			
Ethyl 3-pyridinecarboxylate	3.35(+1)			
Ethyl 4-pyridinecarboxylate	3.45(+1)			
2-Ethylpyridine-1-oxide	−1.19(+1)			
3-Ethylpyridine-1-oxide	−0.965(+1)			
Ethylpyrrolidine	10.43(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Ethyl-2-pyrroline	7.87(+1)			
Ethylsuccinic acid	4.08(0)			
S-Ethylthioacetic acid	5.06			
N-Ethyl-*o*-toluidine	4.92(+1)			
N-Ethylveratramine	7.40(+1)			
β-Eucaine	9.35(+1)			
Fluoroacetic acid	2.586			
2-Fluoroacrylic acid	2.55			
2-Fluoroaniline	3.20(+1)			
3-Fluoroaniline	3.58(+1)			
4-Fluoroaniline	4.65(+1)			
2-Fluorobenzoic acid	3.27			
3-Fluorobenzoic acid	3.865			
4-Fluorobenzoic acid	4.14			
Fluoromandelic acid	4.244			
2-Fluorophenol	8.73			
3-Fluorophenol	9.29			
4-Fluorophenol	9.89			
2-Fluorophenoxyacetic acid	3.08			
3-Fluorophenoxyacetic acid	3.08			
4-Fluorophenoxyacetic acid	3.13			
4-Fluorophenylacetic acid	4.25			
2′-Fluorophenylalanine	2.14(+1)	9.01(0)		
3′-Fluorophenylalanine	2.10(+1)	8.98(0)		
4-Fluorophenylalanine	2.13(+1)	9.05(0)		
2-Fluorophenylphosphonic acid	1.64	6.80		
3-Fluorophenylselenic acid	4.34			
4-Fluorophenylselenic acid	4.50			
2-Fluoropyridine	−0.44(+1)			
3-Fluoropyridine	2.97(+1)			
5-Fluorouracil	8.00(0)	ca 13(−1)		
Folic acid (pteroylglutamic acid)	8.26			
Formic acid	3.751			
N-Formylglycine	3.43			
2-Formyl-3-hydroxypyridine (20°C)	3.40(+1)	6.95(OH)		
4-Formyl-3-hydroxypyridine	4.05(+1)	6.77(OH)		
2-Formyl-3-methoxypyridine (20°C)	3.89(+1)	12.95		
Formyl-3-methoxypyridine (20°C)	4.45(+1)	11.7		
D-(−)-Fructose	12.03			
Fumaric acid	3.10	4.60		
2-Furancarboxylic acid (2-furoic acid)	3.164			
D-(+)-Galactose	12.35			
Galactose-1-phosphoric acid	1.00	6.17		
Glucoascorbic acid	4.26	11.58		
D-Gluconic acid	3.86			
α-**D**-(+)-Glucose	12.28			
α-**D**-Glucose-1-phosphate	1.11(0)	6.504(−1)		
trans-Glutaconic acid	3.77	5.08		
D-(−)-Glutamic acid	2.162(+1)	4.272(0)	9.358(−1)	
L-Glutamic acid	2.19(+1)	4.25(0)	9.67(−1)	

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Glutamic acid, 1-ethyl ester	3.85(+1)	7.84(0)		
Glutamic acid, 5-ethyl ester	2.15(+1)	9.19(0)		
L-Glutamine ($\mu = 0.2$)	2.17(+1)	9.13(0)		
Glutaric acid	3.77	6.08		
Glutaric acid monoamide	4.600(0)			
Glutarimide	11.43			
Glutathione	2.12(+1)	3.53(0)	8.66	9.12
DL-Glyceric acid	3.64			
Glycerol	14.15			
Glyceryl-1-phosphoric acid	——	6.656(−1)		
Glyceryl-2-phosphoric acid	1.335(0)	6.650(−1)		
Glycine	2.341(+1)	9.60(0)		
Glycine amide	8.03(+1)			
Glycine, ethyl ester	7.66(+1)			
Glycine hydroxamic acid	7.10	9.10		
Glycine, methyl ester	7.59(+1)			
Glycine-*O*-phenylphosphorylserine	2.96	8.07		
Glycolic acid	3.831			
N-Glycl-α-alanine	3.15(+1)	8.33(0)		
Glycylalanylalanine	3.38(+1)	8.10(0)		
N-Glycylasparagine	2.942			
Glycyclaspartic acid	2.81(+1)	4.45(0)	8.60(−1)	
Glycyl-**DL**-glutamine (18°C)	2.88(+1)	8.33(0)		
N-Glycylglycine	3.126(+1)	8.252(0)		
Glycylglycylcysteine (35°C)	2.71	2.71	7.94	7.94
Glycylglycylglycine	3.225(+1)	8.090(0)		
Glycyl-**L**-histidine ($\mu = 0.16$)	6.79	8.20		
Glycylisoleucine	8.00			
N-Glycyl-**L**-leucine	3.180(+1)	8.327(0)		
Glycyl-*O*-phosphorylserine	2.90	6.02	8.43	
L-Glycylproline ($\mu = 0.1$)	2.81(+1)	8.65(0)		
N-Glycylsarcosine ($\mu = 0.1$)	2.98(+1)	8.55(0)		
N-Glycylserine	2.98(+1)	8.38(0)		
Glycylserylglycine	3.32	7.99		
Glycyltyrosine	2.93	8.45	10.49	
Glycylvaline	3.15	8.18		
Glyoxaline	7.03(+1)			
Glyoxylic acid	3.30(0)			
Guanidineacetic acid	2.82(+1)			
Guanine	3.3(+1)	9.2	12.3	
Guanine deoxyriboside-3′-phosphoric acid	——	2.9	6.4	9.7
Guanosine	1.9(+1)	9.25(0)	12.33(OH)	
Guanosine-5′-diphosphoric acid ($\mu = 0.1$; pK_5 9.6)	——	——	2.9	6.3
Guanosine-3′-phosphoric acid	0.7	2.3	5.92	9.38
Guanosine-5′-phosphoric acid ($\mu = 0.1$)	——	2.4	6.1	9.4
Guanosine-5′-triphosphoric acid [$\mu = 0.1$; pK_5 7.10(−3); pK_6 9.3(−4)]	——	——	——	3.0(−2)
Guanylurea	1.80	8.20		
Harmine (20°C)	7.61(+1)			
Heptafluorobutanoic acid	0.17			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4,4,5,5,6,6,6-Heptafluorohexanoic acid	4.18			
4,4,5,5,6,6,6-Heptafluoro-2-hexenoic acid	3.23			
Heptanedioic acid (pimelic acid)	4.484	5.424		
2,4-Heptanedione	8.43(keto); 9.15(enol)			
Heptanoic acid	4.893			
Heroin	7.6(+1)			
2,4-Hexadienoic acid (sorbic acid)	4.77			
1,1,1,3,3,3-Hexafluoro-2,2-propanediol	8.801			
1,1,1,3,3,3-Hexafluoro-2-propanol	9.42			
Hexahydroazepine	11.07			
Hexamethyldisilazine	7.55			
1,2,3,8,9,10-Hexamethyl-4,7-phenanthroline (20°C)	7.26			
1,6-Hexanediamine	9.830(+2)	10.930(+1)		
1,6-Hexanedioic acid	4.418	5.412		
2,4-Hexanedione	8.49 (enol); 9.32 (keto)			
2,2′,4,4′,6,6′-Hexanitrodiphenylamine	5.42(+1)			
Hexanoic acid (20°C)	4.849			
trans-2-Hexenoic acid	4.74			
trans-3-Hexenoic acid	4.72			
3-Hexen-4-oic acid	4.58			
4-Hexen-5-oic acid	4.74			
Hexylamine	10.64(+1)			
Hexylarsonic acid	4.16	9.19		
Hexylphosphonic acid	2.6	7.9		
DL-Histidine	1.82(+2)	6.00(+1)	9.16(0)	
Histidine amide ($\mu = 0.2$)	5.78(+2)	7.64(+1)		
Histidine, methyl ester ($\mu = 0.1$)	5.01(+2)	7.23(+1)		
Histidylglycine	2.40(+2)	5.80(+1)	7.82(0)	
Histidylhistidine ($\mu = 0.16$)	5.40(+2)	6.80(+1)	7.95(0)	
DI-Homatropine	9.7(+1)			
DI-Homocysteine	2.222(+1)	8.87	10.86	
Homocysteine ($\mu = 0.1$)	1.593(+2)	2.523(+1)	8.676(0)	9.413(−1)
Hydantoin	9.12			
Hydrastine	6.23(+1)			
Hydrazine-*N*,*N*-diacetic acid	<0.1	2.8	3.8	
Hydrazine-*N*′-*N*′-diacetic acid	2.40	3.12	7.32	
4-Hydrazinocarbonylpyridine (20°C)	1.82	3.52	10.79	
N-Hydroxyacetamide	9.40			
2′-Hydroxyacetophenone	9.90			
3′-Hydroxyacetophenone	9.19			
4′-Hydroxyacetophenone	8.05			
1-Hydroxyacridine (15°C)	5.72			
2-Hydroxyacridine (15°C)	5.62			
3-Hydroxyacridine (15°C)	5.30			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
α-Hydroxyasparagine	2.28(+1)	7.20(0)		
β-Hydroxyasparagine	2.09(+1)	8.29(0)		
Hydroxyaspartic acid	1.91(+1)	3.51(0)	9.11(−1)	
2-Hydroxybenzaldehyde (salicylaldehyde)	8.34			
3-Hydroxybenzaldehyde	9.00			
4-Hydroxybenzaldehyde	7.620			
2-Hydroxybenzaldehyde oxime	1.37(+1)	9.18	12.11	
2-Hydroxybenzamide	8.36			
2-Hydroxybenzenemethanol (2-hydroxybenzyl alcohol)	9.92			
3-Hydroxybenzenemethanol	9.83			
4-Hydroxybenzenemethanol	9.82			
4-Hydroxybenzenesulfonic acid	——	9.055(−1)		
2-Hydroxybenzohydroxamic acid	5.19			
2-Hydroxybenzoic acid (salicyclic acid)	2.98	12.38		
3-Hydroxybenzoic acid	4.076	9.85		
4-Hydroxybenzoic acid	4.582	9.23		
4-Hydroxybenzonitrile	7.95			
2-Hydroxy-5-bromobenzoic acid	2.61			
2-Hydroxybutanoic acid (30°C)	3.65			
L-3-Hydroxybutanoic acid (30°C)	4.41			
4-Hydroxybutanoic acid (30°C)	4.71			
2-Hydroxy-5-chlorobenzoic acid	2.63			
trans-2′-Hydroxycinnamic acid	4.614			
trans-3′-Hydroxycinnamic acid	4.40			
10-Hydroxycodeine	7.12			
cis-2-Hydroxycyclohexane-1-carboxylic acid	4.796			
trans-2-Hydroxycyclohexane-1-carboxylic acid	4.682			
cis-3-Hydroxycyclohexane-1-carboxylic acid	4.602			
trans-3-Hydroxycyclohexane-1-carboxylic acid	4.815			
cis-4-Hydroxycyclohexane-1-carboxylic acid	4.836			
trans-4-Hydroxycyclohexane-1-carboxylic acid	4.687			
1-Hydroxy-2,4-dihydroxymethylbenzene	9.79			
N-(Hydroxyethyl)biguanide	2.8(+2)	11.53(+1)		
N-(2-Hydroxyethyl)ethylenediamine	7.21(+2)	10.12(+1)		
N′-(2-Hydroxyethyl)ethylenediamine-*N*,*N*,*N*′-triacetic acid	2.39	5.37	9.93	
N-(2-Hydroxyethyl)iminodiacetic acid ($\mu = 0.1$)	2.2	8.65		
N-(2-Hydroxyethyl)piperazine-*N*′-ethansulfonic acid (20°C)	7.55			
4′-(2-Hydroxyethyl)-1′-piperazinepropanesulfonic acid (20°C)	8.00			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Hydroxyethyltrimethylamine	8.94(+1)			
L-β-Hydroxyglutamic acid	2.09	4.18	9.20	
1-Hydroxy-4-hydroxymethylbenzene	9.84			
5-Hydroxy-2-(hydroxymethyl)-4*H*-pyran-4-one	7.90	8.03		
3-Hydroxy-2-hydroxymethylpyridine (20°C, $\mu = 0.2$)	5.00(+1)	9.07(OH)		
3-Hydroxy-4-hydroxymethylpyridine (20°C, $\mu = 0.2$)	5.00(+1)	8.95(OH)		
8-Hydroxy-7-iodoquinoline-5-sulfonic acid	2.51(0)	7.417(−1)		
Hydroxylysine (38°C, $\mu = 0.1$)	2.13(+2)	8.62(+1)	9.67(0)	
2-Hydroxy-3-methoxybenzaldehyde	7.912			
3-Hydroxy-4-methoxybenzaldehyde (isovanillin)	8.889			
4-Hydroxy-3-methoxybenzaldehyde (vanillin)	7.396			
4-Hydroxy-3-methoxybenzoic acid	4.355			
1-Hydroxy-2-methoxybenzylamine	8.70(+1)	10.52(0)		
2-Hydroxy-1-methoxybenzylamine	8.89(+1)	10.52(0)		
3-Hydroxy-2-methoxybenzylamine	8.94(+1)	10.42(0)		
2-Hydroxymethyl-2-benzeneacetic acid	4.12			
(2-Hydroxy-5-methylbenzene)-methanol	10.15			
2-Hydroxy-3-methylbenzoic acid	2.99			
2-Hydroxy-4-methylbenzoic acid	3.17			
2-Hydroxy-5-methylbenzoic acid	4.08			
2-Hydroxy-6-methylbenzoic acid	3.32			
2-Hydroxy-2-methylbutanoic acid (18°C)	3.991			
3-Hydroxy-2-methylbutanoic acid (18°C)	4.648			
4-Hydroxy-4-methylpentanoic acid (18°C)	4.873			
1-Hydroxymethylphenol	9.95			
Hydroxymethylphosphoric acid	1.91	7.15		
2-Hydroxy-2-methylpropanoic acid ($\mu = 0.1$)	3.717			
2-Hydroxy-4-methylpyridine	4.529(+1)			
8-Hydroxy-2-methylquinoline	5.55(+1)	10.31(0)		
8-Hydroxy-4-methylquinoline	5.56(+1)	10.00(0)		
8-Hydroxy-2-methylquinoline-5-sulfonic acid	4.80(0)	9.30(−1)		
8-Hydroxy-4-methylquinoline-7-sulfonic acid	4.78(0)	10.01(−1)		
8-Hydroxy-6-methylquinoline-5-sulfonic acid	4.20(0)	8.7(−1)		
2-Hydroxy-1-naphthoic acid (20°C)	3.29	9.68		
2-Hydroxy-2-nitrobenzoic acid	2.23			
2-Hydroxy-3-nitrobenzoic acid	1.87			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Hydroxy-5-nitrobenzoic acid	2.12			
2-Hydroxy-6-nitrobenzoic acid	2.24			
2-Hydroxy-4-nitrophenylphosphonic acid	1.22	5.39		
8-Hydroxy-7-nitroquinoline-5-sulfonic acid	1.94(0)	5.750(−1)		
3-Hydroxy-4-nitrotoluene (μ = 0.1)	7.41			
4-Hydroxypentanoic acid (18°C)	4.686			
4-Hydroxy-3-pentenoic acid	4.30			
3-Hydroxyphenazine (15°C)	2.67			
4-Hydroxyphenylarsonic acid	3.89	8.37 (phenol)	10.05	
3-Hydroxyphenylboric acid	8.55	10.84		
2-Hydroxy-2-phenylpropanoic acid	3.532			
2-(2-Hydroxyphenyl)pyridine (20°C)	4.19(+1)	10.64		
trans-4-Hydroxyproline	1.818(+1)	9.662(0)		
Hydroxypropanedioic acid (tartronic acid)	2.37	4.74		
2-Hydroxypropanoic acid	3.858			
1-Hydroxy-2-propylbenzene	10.50			
4-Hydroxypteridine	1.3(+1)	7.89(0)		
2-Hydroxypyridine	1.25(+1)	11.62(0)		
3-Hydroxypyridine	4.80(+1)	8.72(0)		
4-Hydroxypyridine	3.23(+1)	11.09(0)		
2-Hydroxypyridine-*N*-oxide	−0.62(+1)	5.97(0)		
2-Hydroxypyrimidine	2.24(+1)	9.17(0)		
4-Hydroxypyrimidine	1.85(+1)	8.59(0)		
8-Hydroxyquinazoline	3.41(+1)	8.65(0)		
2-Hydroxyquinoline (20°C)	−0.31(+1)	11.74		
3-Hydroxyquinoline (20°C)	4.30(+1)	8.06(0)		
4-Hydroxyquinoline (20°C)	2.27(+1)	11.25(0)		
5-Hydroxyquinoline (20°C)	5.20(+1)	8.54(0)		
6-Hydroxyquinoline (20°C)	5.17(+1)	8.88(0)		
7-Hydroxyquinoline (20°C)	5.48(+1)	8.85(0)		
8-Hydroxyquinoline (20°C)	4.91(+1)	9.81(0)		
8-Hydroxyquinoline-5-sulfonic acid	4.092(+1)	8.776(0)		
DL-Hydroxysuccinic acid (malic acid)	3.458	5.097		
L-Hydroxysuccinic acid	3.40	5.05		
Hydroxytetracycline	3.27(+1)	7.32(0)	9.11(−1)	
5-Hydroxy-1,2,3,4-tetrazole	3.32			
4-Hydroxy-3-(2′-thiazolyazo)toluene	8.36			
2-Hydroxytoluene	10.33			
3-Hydroxytoluene	10.10			
4-Hydroxytoluene	10.276			
4-Hydroxy-α,α,α-trifluorotoluene	8.675			
1-Hydroxy-2,4,6-trihydroxymethylbenzene	9.56			
Hydroxyuracil	8.64			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Hydroxyvaline	2.55(+1)	9.77(0)		
Hyoscyamine	9.68(+1)			
Hypoxanthene	1.79(+1)	8.91(0)	12.07(−1)	
Hypoxanthine	5.3			
Imidazole	6.993(+1)	10.58(0)		
Imidazolidinetrione (parabanic acid)	6.10			
4-(4-Imidazolyl)butanoic acid (μ = 0.1)	4.26(+1)	7.26(0)		
2-(4-Imidazolyl)ethylamine	5.784(+2)	9.756(+1)		
3-(4-Imidazolyl)propanoic acid (μ = 0.16)	3.96(+1)	7.57(0)		
3,3′-Iminobispropanoic acid	4.11(0)	9.61(−1)		
3,3′-Iminobispropylamine (30°C)	8.02(+2)	9.70(+1)	10.70(0)	
2,2′-Iminodiacetic acid (diglycine) (30°C, μ = 0.1)	2.54(0)	9.12(−1)		
4-Indanol	10.32			
Indole-3-acetic acid	4.75			
Inosine	ca 1.5(+1)	8.96(0)	12.36	
Inosine-5′-phosphoric acid	1.54(0)	6.66(−1)		
Inosine-5′-triphosphoric acid [pK_5 7.68(−4)]	——	——	2.2(−2)	6.92(−3)
Iodoacetic acid	3.175			
2-Iodoaniline	2.54(+1)			
3-Iodoaniline	3.58(+1)			
4-Iodoaniline	3.82(+1)			
2-Iodobenzoic acid	2.86			
3-Iodobenzoic acid	3.86			
4-Iodobenzoic acid	4.00			
5-Iodohistamine	4.06(+1) (imidazole)	9.20(+1) (NH_3^+)	11.88(0) (imino)	
7-Iodo-8-hydroxyquinoline-5-sulfonic acid	2.514	7.417		
Iodomandelic acid	3.264			
Iodomethylphosphoric acid	1.30	6.72		
2-Iodophenol	8.464			
3-Iodophenol	8.879			
4-Iodophenol	9.200			
2-Iodophenoxyacetic acid	3.17			
3-Iodophenoxyacetic acid	3.13			
4-Iodophenoxyacetic acid	3.16			
2-Iodophenylacetic acid	4.038			
3-Iodophenylacetic acid	4.159			
4-Iodophenylacetic acid	4.178			
2-Iodophenylphosphoric acid	1.74	7.06		
2-Iodopropanoic acid	3.11			
3-Iodopropanoic acid	4.08			
2-Iodopyridine	1.82(+1)			
3-Iodopyridine	3.25(+1)			
4-Iodopyridine (20°C)	4.02(+1)			
Isoasparagine	2.97(+1)	8.02(0)		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Isobutylacetic acid (18°C)	4.79			
Isobutylamine	10.41(+1)			
Isochlorotetracycline	3.1(+1)	6.7(0)	8.3(−1)	
Isocreatine	2.84(+1)			
Isogluatamine	3.81(+1)	7.88(0)		
Isohistamine ($\mu = 0.1$)	6.036(+2)	9.274(+1)		
L-Isoleucine	2.35(+1)	9.68(0)		
Isolysergic acid	3.33(0)	8.46(NH)		
Isopilocarpine (15°C)	7.18(+1)			
2-(Isopropoxy)benzoic acid (20°C)	4.24			
3-(Isopropoxy)benzoic acid (20°C)	4.15			
4-(Isopropoxy)benzoic acid (20°C)	4.68			
Isopropylamine	10.64(+1)			
N-Isopropylaniline	5.50(+1)			
5-Isopropylbarbituric acid	4.907(+1)			
2-Isopropylbenzene acid	3.64			
4-Isopropylbenzene acid	4.36			
N-Isopropylglycine ($\mu = 0.1$)	2.36(+1)	10.06(0)		
Isopropylmalonic acid	2.94	5.88		
Isopropylmalonic acid mononitrile	2.401			
3-Isopropyl-4-(methylamino)pyridine (20°C)	9.96(+1)			
3-Isopropylpentanedioic acid	4.30	5.51		
4-Isopropylphenylacetic acid	4.391			
Isopropylphosphinic acid	3.56			
Isopropylphosphonic acid	2.66	8.44		
2-Isopropylpyridine	5.83(+1)			
3-Isopropylpyridine (20°C)	5.72(+1)			
4-Isopropylpyridine	6.02(+1)			
DL-Isoproterenol	8.64(+1)			
Isoquinoline	5.40(+1)			
Isoretronecanol	10.83			
L-Isoserine ($\mu = 0.16$)	2.72(+1)	9.25(0)		
Isothiocyanatoacetic acid	6.62			
L-(+)-Lactic acid	3.858			
L-Leucine	2.33(+1)	9.60(0)		
Leucine amide	7.80(+1)			
Leucine, ethyl ester ($\mu = 0.1$)	7.57(+1)			
L-Leucyl-**L**-asparagine	3.00(+1)	8.12(0)		
L-Leucyl-**L**-glutamine	2.99(+1)	8.11(0)		
DL-Leucylglycine	3.25(+1)	8.28(0)		
Leucylisoserine (20°C)	3.188(+1)	8.207(0)		
D-Leucyl-**L**-tyrosine	3.12(+1)	8.38(0)	10.35(−1)	
L-Leucyl-**L**-tyrosine	3.46(+1)	7.84(0)	10.09(−1)	
Lysergic acid	3.44(+1)	7.68(0)		
L-(+)-Lysine	2.18(+2)	8.94(+1)	10.53(0)	
Lysine, methyl ester ($\mu = 0.1$)	6.965(+1)	10.251(0)		
L-Lysyl-**L**-alanine	3.22(+1)	7.62(0)	10.70(−1)	
L-Lysyl-**D**-alanine	3.00(+1)	7.74(0)	10.63(−1)	
Lysylglutamic acid	2.93(+2)	4.47(+1)	7.75(0)	10.50(+1)
L-Lysyl-**L**-lysine ($\mu = 0.1$)	3.01(+2)	7.53(+1)	10.05(0)	10.01(−1)

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
L-Lysyl-**D**-lysine ($\mu = 0.1$)	2.85(+2)	7.53(+1)	9.92(0)	10.89(−1)
L-Lysyl-**L**-lysyl-**L**-lysine ($\mu = 0.1$)	3.08(+2)	7.34(+1)	9.80(0)	10.54(−1)
L-Lysyl-**D**-lysyl-**L**-lysine ($\mu = 0.1$)	2.91(+2)	7.29(+1)	9.79(0)	10.54(−1)
L-Lysyl-**D**-lysyl-lysine ($\mu = 0.1$)	2.94(+2)	7.15(+1)	9.60(0)	10.38(−1)
α-**D**-Lyxose	12.11			
Maleic acid	1.910	6.33		
Malonamic acid	3.641(0)			
Malonic acid	2.826	5.696		
Malonitrile (cyanoacetic acid)	2.460			
Mandelic acid	3.411			
D-(+)-Mannose	12.08			
Mercaptoacetic acid (thioglycolic acid)	3.60(0)	10.56(SH)		
2-Mercaptobenzoic acid (20°C)	4.05(0)			
2-Mercaptobutanoic acid	3.53(0)			
Mercaptodiacetic acid	3.32	4.29		
2-Mercaptoethanesulfonic acid (20°C)		9.5(−1)		
2-Mercaptoethanol	9.88			
2-Mercaptoethylamine	8.27(+1)	10.53(0)		
2-Mercaptohistidine	1.84(+1)	8.47(0)	11.4(SH)	
Mercapto-*S*-phenylacetic acid ($\mu = 0.1$)	3.9			
2-Mercaptopropane ($\mu = 0.1$)	10.86			
3-Mercapto-1,2-propanediol ($\mu = 0.5$)	9.43			
2-Mercaptopropanoic acid	4.32(0)	10.20(SH)		
3-Mercaptopropanoic acid	——	10.84(SH)		
2-Mercaptopyridine (20°C)	−1.07(+1)	10.00(0)		
3-Mercaptopyridine (20°C)	2.26(+1)	7.03(0)		
4-Mercaptopyridine (20°C)	1.43(+1)	8.86(0)		
2-Mercaptoquinoline (20°C)	−1.44(+1)	10.21(0)		
3-Mercaptoquinoline (20°C)	2.33(+1)	6.13(0)		
4-Mercaptoquinoline (20°C)	0.77(+1)	8.83(0)		
Mercaptosuccinic acid	3.30(0)	4.94(−1)	10.94(SH)	
Mesitylenic acid	4.32			
Mesoxaldialdehyde	3.60			
Methacrylic acid	4.66			
Methanethiol	10.70			
DL-Methionine	2.28(+1)	9.21(0)		
2-(*N*-Methoxyacetamido)pyridine	2.01(+1)			
3-(*N*-Methoxyacetamido)pyridine	3.52(+1)			
4-(*N*-Methoxyacetamido)pyridine	4.62(+1)			
Methoxyacetic acid	3.570			
3-Methoxy-**D**-α-alanine	2.037(+1)	9.176(0)		
2-Methoxyaniline	4.53(+1)			
3-Methoxyaniline	4.20(+1)			
4-Methoxyaniline	5.36(+1)			
2-Methoxybenzoic acid	4.09			
3-Methoxybenzoic acid	4.08			
4-Methoxybenzoic acid	4.49			
N,*N*-Methoxybenzylamine	9.68(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Methoxycarbonylaniline	2.23(+1)			
3-Methoxycarbonylaniline	3.64(+1)			
4-Methoxycarbonylaniline	2.38(+1)			
Methoxycarbonylmethylamine	7.66(+1)			
2-Methoxycarbonylpyridine	2.21(+1)			
3-Methoxycarbonylpyridine	3.13(+1)			
4-Methoxycarbonylpyridine	3.26(+1)			
trans-2-Methoxycinnamic acid	4.462			
trans-3-Methoxycinnamic acid	4.376			
trans-4-Methoxycinnamic acid	4.539			
2-Methoxyethylamine	9.45(+1)			
2-Methoxy-4-nitrophenylphosphonic acid	1.53	6.96		
2-Methoxyphenol	9.99			
3-Methoxyphenol	9.652			
4-Methoxyphenol	10.20			
(2′-Methoxy)phenoxyacetic acid	3.231			
(3′-Methoxy)phenoxyacetic acid	3.141			
(4′-Methoxy)phenoxyacetic acid	3.213			
4′-Methoxyphenylacetic acid	4.358			
(4-Methoxyphenyl)phosphinic acid (17°C)	2.35			
(2-Methoxyphenyl)phosphonic acid	2.16	7.77		
(4-Methoxyphenyl)phosphonic acid (17°C)	2.4	7.15		
3-(2′-Methoxyphenyl)propanoic acid	4.804			
3-(3′-Methoxyphenyl)propanoic acid	4.654			
3-(4′-Methoxyphenyl)propanoic acid	4.689			
3-Methoxyphenylselenic acid	4.65			
4-Methoxyphenylselenic acid	5.05			
2-Methoxy-4-(2-propenyl)phenol	10.0			
2-Methoxypyridine	3.06(+1)			
3-Methoxypyridine	4.91(+1)			
4-Methoxypyridine	6.47(+1)			
4-Methoxy-2-(2′-thiazoylazo)phenol	7.83			
2-Methylacrylic acid (18°C)	4.66			
N-Methylalanine	2.22(+1)	10.19(0)		
O-Methylallothreonine ($\mu = 0.1$)	1.92(+1)	8.90(0)		
Methylamine	10.62(+1)			
2-(*N*-Methylamino)benzoic acid	1.93(+1)	5.34(0)		
3-(*N*-Methylamino)benzoic acid	——	5.10(0)		
4-(*N*-Methylamino)benzoic acid	——	5.05		
Methylaminodiacetic acid (20°C)	2.146	10.088		
2-(Methylamino)ethanol	9.88(+1)			
2-(2-Methylaminoethyl)pyridine (30°C)	3.58(+2)	9.65(+1)		
2-(Methylaminomethyl)6-methylpyridine ($\mu = 0.5$)	3.03(+2)	9.15(+1)		
2-(Methylaminomethyl)pyridine (30°C)	2.92(+2)	8.82(+1)		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4-Methylamino-3-methylpyridine (20°C)	9.83(+1)			
(3-Methylamino)phenylphosphonic acid	1.1(+1)	4.72(+1)	7.30(−1)	
(4-Methylamino)phenylphosphonic acid	——	——	7.85(−1)	
3-(Methylamino)pyridine (30°C)	8.70(+1)			
4-(Methylamino)pyridine (20°C)	9.65(+1)			
4-(Methylamino)-2,3,5,6-tetramethylpyridine (20°C)	10.06(+1)			
N-Methylaniline	4.85(+1)			
Methylarsonic acid (18°C)	3.41	8.18		
1-Methylbarbituric acid	4.35(+1)			
5-Methylbarbituric acid	3.386(+1)			
2-(*N*-Methylbenzamido)pyridine	1.44(+1)			
3-(*N*-Methylbenzamido)pyridine	3.66(+1)			
4-(*N*-Methylbenzamido)pyridine	4.68(+1)			
2-Methylbenzimidazole ($\mu = 0.16$)	6.29(+1)			
2-Methylbenzoic acid (*o*-toluic acid)	3.90			
3-Methylbenzoic acid	4.269			
4-Methylbenzoic acid	4.362			
N-Methyl-1-benzoylecgonine	8.65			
Methylbiguanidine	3.00(+2)	11.44(+1)		
2-Methyl-2-butanethiol	11.35			
2-Methylbutanoic acid	4.761			
3-Methylbutanoic acid (20°C)	4.767			
(*E*)-2-Methyl-2-butendioic acid (mesaconic acid)	3.09	4.75		
3-Methyl-2-butenoic acid	5.12			
(*E*)-2-Methyl-2-butenoic acid (tiglic acid)	4.96			
(*Z*)-2-Methyl-2-butenoic acid (angelic acid)	4.30			
4-Methylcarboxylphenol	8.47			
(*E*)-2-Methylcinnamic acid	4.500			
(*E*)-3-Methylcinnamic acid	4.442			
(*E*)-4-Methylcinnamic acid	4.564			
1-Methylcyclohexane-1-carboxylic acid	5.13			
cis-2-Methylcyclohexane-1-carboxylic acid	5.03			
trans-2-Methylcyclohexane-1-carboxylic acid	5.73			
cis-3-Methylcyclohexane-1-carboxylic acid	4.88			
trans-3-Methylcyclohexane-1-carboxylic acid	5.02			
cis-4-Methylcyclohexane-1-carboxylic acid	5.04			
trans-4-Methylcyclohexane-1-carboxylic acid	4.89			
2-Methylcyclohexyl-1,1-diacetic acid	3.53	6.89		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
3-Methylcyclohexyl-1,1-diacetic acid	3.49	6.08		
4-Methylcyclohexyl-1,1,1-diacetic acid	3.49	6.10		
3-Methylcyclopentyl-1,1-diacetic acid	3.79	6.74		
S-Methyl-L-cysteine	8.97			
N-Methylcytidine	3.88			
5-Methylcytidine	4.21			
N-Methyl-2′-deoxycytidine	3.97			
5-Methyl-2′-deoxycytidine	4.33			
2-Methyl-3,5-dinitrobenzoic acid	2.97			
5-Methyldipropylenetriamine (30°C)	6.32(+3)	9.19(+2)	10.33(+1)	
2,2′-Methylenebis(4-chlorophenol)	7.6	11.5		
2,2′-Methylenebis(4,6-dichlorophenol)	5.6	10.56		
Methylenebis(thioacetic acid (18°C)	3.310	4.345		
3,3′-(Methylenedithio)dialanine	2.200(+1)	8.16(0)		
Methylenesuccinic acid	3.85	5.45		
N-Methylethylamine	4.23(+1)			
N-Methylethylenediamine	6.86(+1)	10.15(+1)		
α-Methylglucoside	13.71			
3-Methylglutaric acid	4.24	5.41		
N-Methylglycine (sarcosine)	2.12(+1)	10.20(0)		
5-Methyl-2,4-heptanedione	8.52(enol); 9.10(keto)			
5-Methyl-2,4-hexanedione	8.66(enol); 9.31(keto)			
5-Methyl-4-hexenoic acid	4.80			
3-Methylhistamine	5.80(+1)	9.90(0)		
1-Methylhistidine	1.69	6.48	8.85	
2-Methylhistidine (18°C)	1.7	7.2	9.5	
2-Methyl-8-hydroxyquinoline (μ = 0.005)	4.58(+1)	11.71(0)		
4-Methyl-8-hydroxyquinoline	4.67(+1)	11.62(0)		
1-Methylimidazole	7.06(+1)			
4-Methylimidazole	7.55(+1)			
N-Methyliminodiacetic acid	2.15	10.09		
S-Methylisothiourea	9.83(+1)			
O-Methylisourea	9.72(+1)			
Methylmalonic acid	3.07	5.87		
2-(*N*-Methylmethanesulfonamido)pyridine	1.73(+1)			
3-(*N*-Methylmethanesulfonamido)pyridine	3.94(+1)			
4-(*N*-Methylmethanesulfonamido)pyridine	5.14(+1)			
2-Methyl-6-methylaminopyridine (20°C)	3.17(+1)	8.84(0)		
3-Methyl-4-methylaminopyridine (20°C)	——	9.84(0)		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4-Methyl-2,2′-(4-methylpyridyl)pyridine	5.32(+1)			
N-Methylmorpholine	7.13(+1)			
2-Methyl-1-naphthoic acid	3.11			
N-Methyl-1-naphthylamine	3.70(+1)			
2-Methyl-4-nitrobenzoic acid	1.86			
2-Methyl-6-nitrobenzoic acid	1.87			
1-Methyl-2-nitroterephthalic acid	3.11			
4-Methyl-2-nitroterephthalic acid	1.82			
3-Methylpentanedioic acid	4.25	5.41		
3-Methylpentane-2,4-dione	10.87			
2-Methylpentanoic acid	4.782			
3-Methylpentanoic acid	4.766			
4-Methylpentanoic acid	4.845			
cis-3-Methyl-2-pentenoic acid	5.15			
trans-3-Methyl-2-pentenoic acid	5.13			
4-Methyl-2-pentenoic acid	4.70			
4-Methyl-3-pentenoic acid	4.60			
6-Methyl-1,10-phenanthroline	5.11(+1)			
(2-Methylphenoxy)acetic acid	3.227			
(3-Methylphenoxy)acetic acid	3.203			
(4-Methylphenoxy)acetic acid	3.215			
(2-Methylphenyl)acetic acid (18°C)	4.35			
(4-Methylphenyl)acetic acid	4.370			
5-Methyl-5-phenylbarbituric acid	8.011(0)			
3-(2-Methylphenyl)propanoic acid	4.66			
3-(3-Methylphenyl)propanoic acid	4.677			
3-(4-Methylphenyl)propanoic acid	4.684			
1-Methyl-2-phenylpyrrolidine	8.80			
5-Methyl-1-phenyl-1,2,3-triazole-4-carboxylic acid	3.73			
Methylphosphinic acid	3.08			
Methylphosphonic acid	2.38	7.74		
3-Methyl-*o*-phthalic acid	3.18			
4-Methyl-*o*-phthalic acid	3.89			
N-Methylpiperazine ($\mu = 0.1$)	4.94(+2)	9.09(+1)		
2-Methylpiperazine	5.62(+2)	9.60(+1)		
N-Methylpiperidine	10.19(+1)			
2-Methylpiperidine	10.95(+1)			
3-Methylpiperidine	11.07(+1)			
4-Methylpiperidine ($\mu = 0.5$)	11.23(+1)			
2-Methyl-1,2-propanediamine	6.178(+2)	9.420(+1)		
2-Methyl-2-propanethiol	11.2			
2-Methylpropanoic acid	4.853			
2-Methyl-2-propylamine	10.682(+1)			
2-Methyl-2-propylglutaric acid	3.626			
2-Methylpyridine	5.96(+1)			
3-Methylpyridine	5.68(+1)			
4-Methylpyridine	6.00(+1)			
Methyl 4-pyridinecarboxylate	3.26(+1)			
6-Methylpyridine-2-carboxylic acid	5.83			
2-Methylpyridine-1-oxide	1.029(+1)			
3-Methylpyridine-1-oxide	10.921(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4-Methylpyridine-1-oxide	1.258(+1)			
O-Methylpyridoxal ($\mu = 0.16$)	4.74			
Methyl-2-pyridyl ketoxime	9.97			
1-Methyl-2-(3-pyridyl)pyrrolidine	3.41	7.94		
1-Methylpyrrolidine	10.46(+1)			
1-Methyl-3-pyrroline	9.88(+1)			
5-Methylquinoline	4.62(+1)			
Methylsuccinic acid	4.13	5.64		
Methylsulfonylacetic acid	2.36			
3-Methylsulfonylaniline	2.68(+1)			
4-Methylsulfonylaniline	1.48(+1)			
3-Methylsulfonylbenzoic acid	3.52			
4-Methylsulfonylbenzoic acid	3.64			
4-Methylsulfonyl-3,5-dimethylphenol	8.13			
3-Methylsulfonylphenol	9.33			
4-Methylsulfonylphenol	7.83			
1-Methyl-1,2,3,4-tetrahydro-3-pyridinecarboxylic acid (arecaidine; isoguvacine)	9.07			
5-Methyl-1,2,3,4-tetrazole	3.32			
2-Methylthiazole ($\mu = 0.1$)	3.40(+1)			
4-Methylthiazole ($\mu = 0.1$)	3.16(+1)			
5-Methylthiazole ($\mu = 0.1$)	3.03(+1)			
Methylthioacetic acid	3.72			
4-Methylthioaniline	4.40(+1)			
2-Methylthioethylamine (30°C)	9.18(+1)			
Methylthioglycolic acid	7.68			
3-(*S*-Methylthio)phenol	9.53			
4-(*S*-Methylthio)phenol	9.53			
2-Methylthiopyridine (20°C)	3.59(+1)			
3-Methylthiopyridine (20°C)	4.42(+1)			
4-Methylthiopyridine (20°C)	5.94(+1)			
5-Methylthio-1,2,3,4-tetrazole	4.00(+1)			
O-Methylthreonine	2.02(+1)	9.00(0)		
O-Methyltyrosine	2.21(+1)	9.35(0)		
1-Methylxanthine	7.70	12.0		
3-Methylxanthine	8.10	11.3		
7-Methylxanthine	8.33	ca 13		
9-Methylxanthine	6.25			
Morphine (20°C)	7.87(+1)	9.85(0)		
Morpholine	8.492(+1)			
2-(*N*-Morpholino)ethanesulfonic acid (MES) (20°C)	6.15			
3-(*N*-Morpholino)-2-hydroxypropanesulfonic acid (37°C)	6.75			
3-(*N*-Morpholino)propanesulfonic acid (20°C)	7.20			
Murexide	0.0	9.20	10.50	
Myosmine	5.26			
1-Naphthalenecarboxylic acid (1-naphthoic acid)	3.695			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2-Naphthalenecarboxylic acid	4.161			
1-Naphthol (20°C)	9.30			
2-Naphthol (20°C)	9.57			
Naphthoquinone monoxime	8.01			
1-Naphthylacetic acid	4.236			
2-Naphthylacetic acid	4.256			
1-Naphthylamine	3.92(+1)			
2-Naphthylamine	4.11(+1)			
1-Naphthylarsonic acid	3.66	8.66		
1-Naphthysulfonic acid	0.57			
Narceine (15°C)	3.5(+1)	9.3		
Narcotine	6.18(+1)			
Nicotine	3.15(+1)	7.87(0)		
Nicotyrine	4.76(+1)			
Nitrilotriacetic acid (NTA) (20°C)	1.65	2.94	10.33	
Nitroacetic acid	1.68			
2-Nitroaniline	−0.28(+1)			
3-Nitroaniline	2.46(+1)			
4-Nitroaniline	1.01(+1)			
2-Nitrobenzene-1,4-dicarboxylic acid	1.73			
3-Nitrobenzene-1,2-dicarboxylic acid	1.88			
4-Nitrobenzene-1,2-dicarboxylic acid	2.11			
2-Nitrobenzoic acid	2.18			
3-Nitrobenzoic acid	3.46			
4-Nitrobenzoic acid	3.441			
trans-2-Nitrocinnamic acid	4.15			
trans-3-Nitrocinnamic acid	4.12			
trans-4-Nitrocinnamic acid	4.05			
Nitroethane	8.57			
2-Nitrohydroquinone	7.63	10.06		
N-Nitroiminodiacetic acid	2.21	3.33		
3-Nitromesitol	8.984			
Nitromethane	10.12			
1-Nitro-6,7-phenanthroline (μ = 0.2)	3.23(+1)			
5-Nitro-1,10-phenanthroline	3.232(+1)			
6-Nitro-1,10-phenanthroline	3.23(+1)			
2-Nitrophenol	7.222			
3-Nitrophenol	8.360			
4-Nitrophenol	7.150			
(2-Nitrophenoxy)acetic acid	2.896			
(3-Nitrophenoxy)acetic acid	2.951			
(4-Nitrophenoxy)acetic acid	2.893			
2-Nitrophenylacetic acid	4.00			
3-Nitrophenylacetic acid	3.97			
4-Nitrophenylacetic acid	3.85			
2-Nitrophenylarsonic acid	3.37	8.54		
3-Nitrophenylarsonic acid	3.41	7.80		
4-Nitrophenylarsonic acid	2.90	7.80		
7-(4-Nitrophenylazo)-8-hydroxy-5-quinolinesulfonic acid	3.14(0)	7.495(−1)		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
3-Nitrophenylphosphonic acid	1.30	6.27		
4-Nitrophenylphosphonic acid	1.24	6.23		
3-(2′-Nitrophenyl)propanoic acid	4.504			
3-(4′-Nitrophenyl)propanoic acid	4.473			
3-Nitrophenylselenic acid	4.07			
4-Nitrophenylselenic acid	4.00			
1-Nitropropane	8.98			
2-Nitropropane	7.675			
2-Nitropropanoic acid	3.79			
2-Nitropyridine (μ = 0.02)	−2.06(+1)			
3-Nitropyridine (μ = 0.02)	0.79(+1)			
4-Nitropyridine (μ = 0.02)	1.23(+1)			
N-Nitrosoiminodiacetic acid	2.28	3.38		
4-Nitrosophenol	6.48			
Nitrourea	4.15(+1)			
1,9-Nonanedioic acid (azelaic acid)	4.53	5.40		
Nonanoic acid (pelargonic acid)	4.95			
DL-Norleucine	2.335(+1)	9.834(0)		
Novocaine	8.85(+1)			
2,2,3,3,4,4,5,5-Octafluoropentanoic acid	2.65			
1,8-Octanedioic acid (suberic acid)	4.512	5.404		
Octanoic acid (caprylic acid)	4.895			
Octopine-**DD**	1.35	2.30	8.68	11.25
Octopine-**LD**	1.40	2.30	8.72	11.34
Octylamine	10.65(+1)			
L-(+)-Ornithine	1.94(+2)	8.65(+1)	10.76(0)	
Oxalic acid	1.271	4.272		
3,6-Oxaoctanedioic acid (μ = 1.0)	3.055	3.676		
Oxoacetic acid	3.46			
2-Oxabutanedioic acid (oxaloacetic acid)	2.56	4.37		
2-Oxobutanoic acid	2.50			
5-Oxohexanoic acid (5-ketohexanoic acid) (18°C)	4.662			
3-Oxo-1,5-pentanedioic acid	3.10			
4-Oxopentanoic acid (levulinic acid)	4.59			
2-Oxopropanoic acid (pyruvic acid)	2.49			
Oxytetracycline	3.10(+1)	7.26	9.11	
Papaverine	5.90(+1)			
Pentamethylenebis(thioacetic acid) (18°C)	3.485	4.413		
3,3-Pentamethylenepentanedioic acid	3.49	6.96		
1,5-Pentanediamine	10.05(+2)	10.916(+1)		
2,4-Pentanedione	8.24(enol); 8.95(keto)			
1-Pentanoic acid (valeric acid)	4.842			
2-Pentenoic acid	4.70			
3-Pentenoic acid	4.52			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
4-Pentenoic acid	4.677			
Pentylarsonic acid	4.14	9.07		
N-Pentylveratramine	7.28(+1)			
Perhydrodiphenic acid (20°C)	4.96	6.68		
Perlolidine (18°C)	4.01	11.39		
Peroxyacetic acid	8.20			
1,7-Phenanthroline	4.30(+1)			
1,10-Phenanthroline	4.857(+1)			
6,7-Phenanthroline	4.857(+1)			
Phenazine	1.2(+1)			
Phenethylthioacetic acid	3.795			
Phenol	9.99			
Phenol-3-phosphoric acid	1.78	7.03	10.2	
Phenol-4-phosphoric acid	1.99	7.25	9.9	
Phenolphthalein	9.4			
3-Phenolsulfonic acid	——	9.05(−1)		
Phenosulsulfonephthalein	7.9			
Phenoxyactic acid	3.171			
2-Phenoxybenzoic acid	3.53			
3-Phenoxybenzoic acid	3.95			
4-Phenoxybenzoic acid	4.52			
5-Phenoxy-1,2,3,4-tetrazole	3.49(+1)			
Phenylacetic acid	4.312			
L-3-Phenyl-α-alanine	1.83(+1)	9.12(0)		
3-Phenyl-α-alanine, methyl ester	7.05(+1)			
Phenylalanylarginine (μ = 0.01)	2.66(+1)	7.57(0)	12.40(−1)	
Phenylalanylglycine (μ = 0.01)	3.10(+1)	7.71(0)		
7-Phenylazo-8-hydroxy-5-quinolinesulfonic acid	3.41(0)	7.850(−1)		
5-Phenylbarbituric acid	2.544(+1)			
2-Phenyl-2-benzylsuccinic acid	3.69	6.47		
1-Phenylbiguanide	2.13(+2)	10.76(+1)		
4-Phenylbutanoic acid	4.757			
Phenylbutazone	4.5(+1)			
2-Phenylenediamine	<2(+2)	4.47(+1)		
3-Phenylenediamine	2.65(+2)	4.88(+1)		
4-Phenylenediamine	3.29(+2)	6.08(+1)		
2-Phenylethylamine	9.83(+1)			
β-Phenylethylboronic acid	10.0			
DL-α-Phenylglycine	1.83(+1)	4.39(0)		
Phenylguanidine	10.77(+1)			
Phenylhydrazine	5.20(+1)			
2-Phenyl-3-hydroxypropanoic acid	3.53			
3-Phenyl-3-hydroxypropanoic acid	4.40			
Phenyliminodiacetic acid (20°C)	2.40	4.98		
Phenylmalonic acid	2.58	5.03		
Phenylmethanethiol	10.70			
2-Phenyl-2-phenethylsuccinic acid (20°C)	3.74	6.52		
2-Phenylphenol	9.55			
3-Phenylphenol	9.63			
4-Phenylphenol	9.55			
Phenylphosphinic acid (17°C)	2.1			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Phenylphosphonic acid	1.83	7.07		
O-Phenylphosphorylserine	2.13(+1)	8.79		
O-Phenylphosphorylserylglycine	3.18(+1)	6.95(0)		
O-Phenylphosphoryl-**L**-seryl-**L**-leucine	3.16(+1)	7.12(0)		
N-Phenylpiperazine ($\mu = 0.1$)	8.71(+1)			
2-Phenylpropanoic acid	4.38			
3-Phenylpropanoic acid (35°C)	4.664			
3-Phenyl-1-propylamine	10.39(+1)			
Phenylpropynoic acid (35°C)	2.269			
Phenylselenic acid	4.79			
Phenylselenoacetic acid ($\mu = 0.1$)	3.75			
β-Phenylserine ($\mu = 0.16$)	8.79(0)			
Phenylsuccinic acid (20°C)	3.78	5.55		
Phenylsulfenylacetic acid	2.66			
Phenylsulfonylacetic acid	2.44			
5-Phenyl-1,2,3,4-tetrazole	4.38(+1)			
1-Phenyl-1,2,3-triazole-4-carboxylic acid	2.88			
1-Phenyl-1,2,3-triazole-4,5-dicarboxylic acid	2.13	4.93		
Phosphoramidic acid	3.08	8.63		
O-Phosphorylethanolamine	5.838(+1)	10.638(0)		
O-Phosphorylserylglycine	3.13	5.41	8.01	
O-Phosphoryl-**L**-seryl-**L**-leucine	3.11	5.47	8.26	
Phosphoserine	2.08	5.65	9.74	
Phthalamide	3.79(0)			
Phthalazine	3.47(+1)			
o-Phthalic acid	2.950	5.408		
Phthalimide	9.90(0)			
Physostigmine	1.76(+1)	7.88(0)		
Picric acid (2,4,6-trinitrophenol) (18°C)	0.419			
Pilocarpine	1.3(+1)	6.85(0)		
Piperazine	5.333(+2)	9.781(+1)		
1,4-Piperazinebis(ethanesulfonic acid) (20°C)	6.80			
Piperazine-2-carboxylic acid	1.5	5.41	9.53	
Piperdine	11.123(+1)			
2-Piperidinecarboxylic acid	2.12(+1)	10.75(0)		
3-Piperidinecarboxylic acid	3.35(+1)	10.64(0)		
4-Piperidinecarboxylic acid	3.73(+1)	10.72(0)		
1-(2-Piperidinyl)-2-propanone (15°C)	9.45			
Piperine (15°C)	1.98(+1)			
Proline	1.99(+1)	10.96(0)		
1,2-Propanediamine	6.607(+2)	9.702(+1)		
1,3-Propanediamine	8.49(+2)	10.47(+1)		
1-Propanethiol	10.86			
1,2,3-Propanetriamine	3.72(+3)	7.95(+2)	9.59(+1)	
1,2,3-Propanetricarboxylic acid	3.67	4.87	6.38	
Propanoic acid	4.874			
Propenoic acid	4.247			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
N-Propionylglycine	3.718(0)			
2-Propoxybenzoic acid (20°C)	4.24			
3-Propoxybenzoic acid (20°C)	4.20			
4-Propoxybenzoic acid (20°C)	4.78			
N-Propylalanine	2.21(+1)	10.19(0)		
Propylamine	10.568(+1)			
Propylarsonic acid (18°C)	4.21	9.09		
Propylenimine	8.18(+1)			
N-Propylglycine (μ = 0.1)	2.38(+1)	10.03(0)		
L-Propylglycine	3.19(+1)	8.97(0)		
Propylmalonic acid	2.97	5.84		
Propylphosphinic acid	3.46			
Propylphosphonic acid	2.49	8.18		
2-Propylpyridine	6.30(+1)			
N-Propylveratramine	7.20(+1)			
2-Propynoic acid	1.887			
Pseudoecgonine	9.70			
Pseudoisocyanine (μ = 0.2)	4.59(+2)			
Pseudotropine	9.86(+1)			
Pteroylglutamic acid	8.26			
Purine	2.52(+1)	8.92(0)		
Pyrazine	0.6(+1)			
Pyrazinecarboxamide	0.5(+1)			
Pyrazole	2.61(+1)			
Pyridazine	2.33(+1)			
Pyridine	5.17(+1)			
Pyridine-d_5	5.83(+1)			
2-Pyridinealdoxime	3.56(+1)	10.17(0)		
3-Pyridinealdoxime	4.07(+1)	10.39(0)		
4-Pyridinealdoxime	4.73(+1)	10.03(0)		
2-Pyridinecarbaldehyde	3.84(+1)			
3-Pyridinecarbaldehyde	3.80(+1)			
4-Pyridinecarbaldehyde	4.74(+1)			
3-Pyridinecarbamide (nicotinamide)	3.33(+1)			
3-Pyridinecarbonitrile	1.35(+1)			
Pyridine-2-carboxylic acid (picolinic acid)	1.01(+1)	5.29(0)		
Pyridine-3-carboxylic acid (nicotinic acid)	2.07(+1)	4.75(0)		
Pyridine-4-carboxylic acid (isonicotinic acid)	1.84(+1)	4.86(0)		
Pyridine-2,3-dicarboxylic acid	2.36(+1)	7.08(0)		
Pyridine-2,4-dicarboxylic acid	2.23(+1)	7.02(0)		
Pyridine-2,6-dicarboxylic acid	2.16(+1)	6.92(0)		
Pyridine-1-oxide	0.688(+1)			
Pyridoxal	4.20(+1)	8.66(ring OH)		
Pyridoxal-5-phosphate (μ = 0.15)	<2.5	4.14	6.20	8.69
Pyridoxamine (μ = 0.1)	3.37(+2)	8.01(+1)	10.13(ring OH)	
Pyridoxamine-5-phosphate (μ = 0.15; pK_5 10.92)	2.5	3.69	5.76	8.61

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Pyridoxine (vitamin B_6) (18°C)	5.00(+1)	8.96(ring OH)		
3-(2′-Pyridyl)alanine	1.37(+2)	4.02(+1)	9.22(0)	
3-(3′-Pyridyl)alanine	1.77(+2)	4.64(+1)	9.10(0)	
2-(2′-Pyridyl)benzimidazole (μ = 0.16)	5.58(+1)			
2-(2′-Pyridyl)imidazole (μ = 0.005)	8.98(+1)			
4-(2′-Pyridyl)imidazole (μ = 0.1)	5.49(+1)			
Pyrimidine	1.30(+1)			
2,4(1*H*,3*H*)-Pyrimidinedione (uracil)	0.6(+1)	9.46(0)		
2,4,5,6(1*H*,3*H*)-Pyrimidinetetrone-5-oxime	4.57(0)			
Pyrocatecholsulfonephthaleine	7.82	9.76	11.73	
Pyroxilidine	11.11(+1)			
Pyrrole-1-carboxylic acid	4.45			
Pyrrole-2-carboxylic acid	4.45			
Pyrrole-3-carboxylic acid	4.453			
Pyrrolidine	11.305(+1)			
Pyrrolidine-2-carboxylic acid (proline)	1.952(+1)	10.640(0)		
2-[2-(*N*-Pyrrolidinyl)ethyl]pyridine	3.60(+2)	9.39(+1)		
3-[2-(*N*-Pyrrolidinyl)ethyl]pyridine	4.28(+2)	9.28(+1)		
4-[2-(*N*-Pyrrolidinyl)ethyl]pyridine	4.65(+2)	9.27(+1)		
2-(1-Pyrrolidinylmethyl)pyridine	2.54(+1)	8.56(+1)		
3-(1-Pyrrolidinylmethyl)pyridine	3.14(+2)	8.36(+1)		
4-(1-Pyrrolidinylmethyl)pyridine	3.38(+2)	8.16(+1)		
3-Pyrroline	−0.27(+1)			
Quinidine	4.0(+1)	8.54(0)		
Quinine	4.11(+1)	8.52(0)		
Quinoline	4.80(+1)			
Quinoxaline	0.72(+1)			
D-Raffinose	12.74			
Riboflavin (vitamin B_2) (μ = 0.01)	ca −0.2	9.69		
α-**D**-Ribofuranose	12.11			
D-Ribose-5′-phosphonic acid	——	6.70(−1)	13.05(−2)	
D-Saccharic acid	5.00(0)			
Saccharin (*o*-benzoic sulfimide)	2.32			
Sarcosine	2.12(+1)	10.20(0)		
Sarcosine amide	8.35(+1)			
Sarcosine dimethylamide	8.86(+1)			
Sarcosine methylamide	8.28(+1)			
Sarcosylglycine (μ = 0.16)	3.15(+1)	8.56(0)		
Sarcosylleucine	3.15(+1)	8.67(0)		
Sarcosylsarcosine	2.92(+1)	9.15(0)		
Sarcosylserine	3.17(+1)	8.63(0)		
3-Selenosemicarbazide (μ = 0.1)	0.8(+1)			
Semicarbazide (μ = 0.1)	3.53(+1)			
L-Serine	2.21(+1)	9.15(0)	13.6	

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
Serine, methyl ester ($\mu = 0.1$)	7.03(+1)			
Serylglycine ($\mu = 0.15$)	2.10(+1)	7.33(0)		
L-Seryl-**L**-leucine	3.08(+1)	7.45(0)		
Solanine	7.34(+1)			
D-Sorbitol (17.5°C)	13.60			
L-(−)-Sorbose (18°C)	11.55			
Sparteine	4.49(+1)	11.76(0)		
Spinaceamine ($\mu = 0.1$)	4.895(+2)	8.90(+1)		
Spinacine	1.649(+2)	4.936(+1)	8.663(0)	
L-Strychnine (15°C)	2.50	8.20		
Succinamic acid (succinic acid monoamide)	4.39(0)			
Succinic acid	4.207	5.635		
DL-Succinimide	9.623			
β-(4′-Sulfaminophenyl)alanine	1.99(+1)	8.64(0)	10.26(−1)	
3-Sulfamylbenzoic acid	3.54			
4-Sulfamylbenzoic acid	3.47			
4-Sulfamylphenylphosphoric acid	1.42	6.38	10.0	
Sulfanilamide	10.43(+1)			
Sulfoacetic acid	——	4.0		
3-Sulfobenzoic acid	——	3.78		
4-Sulfobenzoic acid	——	3.72		
3-Sulfophenol	0.39	9.07		
4-Sulfophenol	0.58	8.70		
2-Sulfopropanoic acid	1.99			
5-Sulfosalicyclic acid	2.49	12.00		
Sylvic acid	7.62			
D-Tartaric acid	3.036	4.366		
meso-Tartaric acid	3.22	4.81		
Tetracycline ($\mu = 0.005$)	3.30(+1)	7.68	9.69	
Tetradehydroyohimbine	10.59(+1)			
Tetraethylenepentamine [$\mu = 0.1$; pK_5 9.67(+1)]	2.98(+5)	4.72(+4)	8.08(+3)	9.10(+2)
1,4,5,6-Tetrahydro-1,2-dimethylpyridine	11.38(+1)			
1,4,5,6-Tetrahydro-2-methylpyridine	9.53(+1)			
cis-Tetrahydronaphthalene-2,3-dicarboxylic acid (20°C)	3.98	6.47		
trans-Tetrahydronaphthalene-2,3-dicarboxylic acid (20°C)	4.00	5.70		
5,6,7,8-Tetrahydro-1-naphthol	10.28			
5,6,7,8-Tetrahydro-2-naphthol	10.48			
Tetrahydroserpentine	10.55(+1)			
2,3,5,6-Tetramethylbenzoic acid	3.415			
Tetramethylenebis(thioacetic acid) (18°C)	3.463	4.423		
Tetramethylenediamine	9.22(+2)	10.75(+1)		
N,*N*,*N*′,*N*′-Tetramethylethylenediamine	2.20(+2)	6.35(+1)		
2,3,5,6-Tetramethyl-4-methylaminopyridine	0.07(+1)			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2,2,6,6-Tetramethylpiperidine (μ = 0.5)	1.24(+1)			
2,3,5,6-Tetramethylpyridine (20°C)	7.90(+1)			
Tetramethylsuccinic acid	3.50	7.28		
1,2,3,4-Tetrazole	4.90			
Thebaine	7.95(+1)			
2-Thenoyltriflluoroacetone	5.70(0)			
Theobromine	0.68(+1)	7.89		
Theophylline	<1(+1)	8.80		
Thiazoline	2.53(+1)			
Thioacetic acid	3.33			
o-Thiocresol	6.64			
m-Thiocresol	6.58			
p-Thiocresol	6.52			
Thiocyanatoacetic acid	2.58			
2,2′-Thiodiacetic acid	3.32	4.29		
4,4′-Thiodibutanoic acid (18°C)	4.351	5.275		
3,3′-Thiodipropanoic acid (18°C)	4.085	5.075		
3-Thio-*S*-methylcarbazide (μ = 0.1)	7.563(+1)			
1-Thionylcarboxylic acid	3.53			
2-Thionylcarboxylic acid	4.10			
2-Thiophenecarboxylic acid (30°C)	3.529			
3-Thiophenecarboxylic acid (3-thenoic acid)	4.10			
Thiophenol	6.50			
3-Thiosemicarbazide (μ = 0.1)	1.5(+1)			
3-Thiosemicarbazide-1,1-diacetic acid (30°C)	2.94	4.07		
Thiourea	2.03(+1)			
Thorin	3.7	8.3	11.8	
Thymidine	9.79	12.85		
p-Toluenesulfinic acid	1.7			
Toluhydroquinone	10.03	11.62		
o-Toluidine	4.45(+1)			
m-Toluidine	4.71(+1)			
p-Toluidine	5.08(+1)			
o-Tolylacetic acid (18°C)	4.36			
p-Tolylacetic acid (18°C)	4.36			
o-Tolylarsonic acid	3.82	8.85		
m-Tolylarsonic acid	3.82	8.60		
p-Tolylarsonic acid	3.70	8.68		
o-Tolylphosphonic acid	2.10	7.68		
m-Tolylphosphonic acid	1.88	7.44		
p-Tolylphosphonic acid	1.84	7.33		
3-Tolylselenic acid	4.80			
4-Tolylselenic acid	4.88			
Triacetylmethane	5.81			
Triallylamine	8.31(+1)			
1,3,5-Triazine-2,4,6-triol	7.20	11.10		
1*H*-1,2,3-Triazole	——	9.26		
1*H*-1,2,4-Triazole	2.386(+1)	9.972		
1,2,3-Triazole-4-carboxylic acid	3.22	8.73		

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
1,2,3-Triazole-4,5-dicarboxylic acid	1.86	5.90	9.30	
1,2,4-Triazolidine-3,5-dione (urazole)	5.80			
Tribomoacetic acid	−0.147			
2,4,6-Tribromobenzoic acid	1.41			
Trichloroacetic acid	0.52			
Trichloroacrylic acid	1.15			
3,3,3-Trichlorolactic acid	2.34			
Trichloromethylphosphonic acid	1.63	4.81		
2,4,5-Trichlorophenol	7.37			
3,4,5-Trichlorophenol	7.839			
Tricine (20°C)	8.15			
Triethanolamine	7.76(+1)			
Triethylamine	10.72(+1)			
Triethylenediamine	4.18(+2)	8.19(+1)		
Triethylenetetramine (20°C)	3.32(+4)	6.67(+3)	9.20(+2)	9.92(+1)
Triethylsuccinic acid	2.74			
Trifluoroacetic acid	0.50			
Trifluoroacrylic acid	1.79			
4,4,4-Trifluoro-2-aminobutanoic acid	1.600(+1)	8.169(0)		
4,4,4-Trifluoro-3-aminobutanoic acid	2.756(+1)	5.822(0)		
4,4,4-Trifluorobutanoic acid	4.16			
α,α,α-Trifluoro-*m*-cresol	8.950			
4,4,4-Trifluorocrotonic acid	3.15			
5,5,5-Trifluoroleucine	2.045(+1)	8.942(0)		
3-(Trifluoromethyl)aniline	3.5(+1)			
4-(Trifluoromethyl)aniline	2.6(+1)			
3-Trifluoromethylphenol	8.950			
5-Trifluoromethyl-1,2,3,4-tetrazole	1.70			
6,6,6-Trifluoronorleucine	2.164(+1)	9.463(0)		
5,5,5-Trifluoronorvaline	2.042(+1)	8.916(0)		
5,5,5-Trifluoropentanoic acid	4.50			
3,3,3-Trifluoropropanoic acid	3.06			
4,4,4-Trifluorothreonine	1.554(+1)	7.822(0)		
4,4,4-Trifluorovaline	1.537(+1)	8.098(0)		
1,2,3-Trihydroxybenzene (pyrogallol)	9.03(0)	11.63(−1)		
1,3,5-Trihydroxybenzene (phloroglucinol)	8.45(0)	8.88(−1)		
2,4,6-Trihydroxybenzoic acid	1.68(0)			
3,4,5-Trihydroxybenzoic acid	4.19(0)	8.85(−1)		
3,4,5-Trihydroxycyclohex-1-ene-1-carboxylic acid [D-(−)-shikimic acid]	4.15			
2,4,6-Tri(hydroxymethyl)phenol	9.56			
Triisobutylamine	10.42(+1)			
Trimethylamine	9.80(+1)			
3-(Trimethylamino)phenol	8.06			
4-(Trimethylamino)phenol	8.35			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
2,4,6-Trimethylaniline	4.38(+1)			
2,4,6-Trimethylbenzoic acid	3.448			
Trimethylenebis(thioacetic acid) (18°C)	3.435	5.383		
2,3,4-Trimethylphenol	10.59			
2,4,5-Trimethylphenol	10.57			
2,4,6-Trimethylphenol	10.88			
3,4,5-Trimethylphenol	10.25			
2,3,6-Trimethylpyridine (μ = 0.5)	7.60(+1)			
2,4,6-Trimethylpyridine	7.43(+1)			
2,4,6-Trimethylpyridine-1-oxide	1.990(+1)			
3-(Trimethylsilyl)benzoic acid	4.089			
4-(Trimethylsilyl)benzoic acid	4.192			
2,4,5-Trimethylthiazole (μ = 0.1)	4.55			
2,4,6-Trinitroaniline (picramide)	−10.23(+1)			
2,4,6-Trinitrobenzene acid	0.654			
2,2,2-Trinitroethanol	2.36			
Trinitromethane (20°C)	0.17			
Triphenylacetic acid	3.96			
Tripropylamine	10.66(+1)			
Tris(2-hydroxyethyl)amine	7.762(+1)			
Tri(hydroxymethyl)aminomethane (TRIS)	8.08(+1)			
2-[Tris(hydroxymethyl)methyl amino]-1-ethanesulfonic acid (TES)	7.50			
3-[Tris(hydroxymethyl)methyl amino]-1-propanesulfonic acid (TAPS) (20°C)	8.4			
N-[Tris(hydroxymethyl)methyl]-glycine (tricine)	2.023(+1)	8.135		
Tris(trimethylsilyl)amine	4.70(+1)			
Trithiocarbonic acid (20°C)	2.64			
Tropacocaine (15°C)	9.88(+1)			
3-Tropanol (tropine)	10.33(+1)			
Trypsin (μ = 0.1)	6.25			
L-Tryptophan	2.38(+1)	9.39(0)		
DL-Tyrosine	2.18(+1)	9.11(0)	10.6(OH)	
Tyrosine amide	7.48	9.89		
Tyrosine, ethyl ester	7.33	9.80		
Tyrosylarginine (μ = 0.01)	2.65(+1)	7.39(0)	9.36(−1)	11.62(−2)
Tyrosyltyrosine	3.52(+1)	7.68(0)	9.80(−1)	10.26(−2)
α-Ureidobutanoic acid	3.886(0)			
γ-Ureidobutanoic acid	4.683(0)			
β-Ureidopropanoic acid	4.487(0)			
Uric acid	5.40	5.53		
Uridine	9.30			
Uridine-5′-diphosphoric acid	7.16			
Uridine-5′-phosphoric acid (5′-uridylic acid)	6.63			
Uridine-5′-triphosphoric acid	7.58			

TABLE 8.8 pK_a Values of Organic Materials in Water at 25°C (*Continued*)

Substance	pK_1	pK_2	pK_3	pK_4
DL-Valine	2.32(+1)	9.61(0)		
L-Valine	2.296(+1)	9.79(0)		
Valine amide (μ = 0.2)	8.00			
L-Valine, methyl ester	7.49(+1)			
L-Valylglycine	3.23(+1)	8.00(0)		
Vetramine	7.49(+1)			
Veratrine	8.85(+1)			
Vinylmethylamine	9.69(+1)			
2-Vinylpyridine	4.98(+1)			
4-Vinylpyridine	5.62(+1)			
Vitamin B_{12}	7.64(+1)			
Xanthine (40°C)	0.68(+1)			
Xanthosine	<2.5(+1)	5.67(0)	12.00(−1)	
Xylenol Orange [pK_5 10.46(−4); pK_6 12.28(−5)]	——	2.58(−1)	3.23(−2)	6.37(−3)
D-(+)-Xylose	12.15(0)			
Zincon	——	4	7.85	15

TABLE 8.9 Selected Equilibrium Constants in Aqueous Solution at Various Temperatures

Abbreviations Used in the Table

(+1), protonated cation
(0), neutral molecule
(−1), singly ionized anion
(−2), doubly ionized anion
pK_{auto}, negative logarithm (base 10) of autoprotolysis constant
pK_{sp}, negative logarithm (base 10) of solubility product

Substance	Temperature, °C									
	0	5	10	15	20	25	30	35	40	50
Acetic acid (0)	4.780	4.770	4.762	4.758	4.757	4.756	4.757	4.762	4.769	4.787
DL-*N*-Acetylalanine (+1)		3.699	3.699	3.703	3.708	3.715	3.725	3.733	3.745	3.774
β-Acetylaminopropionic (+1)		4.479	4.465	4.465	4.449	4.445	4.444	4.443	4.445	4.457
N-Acetylglycine (+1)		3.682	3.676	3.673	3.667	3.670	3.673	3.678	3.685	3.706
α-Alanine										
(+1)	2.42		2.39		2.35	2.34	2.33	2.33	2.33	2.33
(0)	10.59		10.29		10.01	9.87	9.74	9.62	9.49	9.26
2-Aminobenzenesulfonic acid (0), pK_2	2.633	2.591	2.556	2.521	2.448	2.459	2.431	2.404	2.380	2.338
3-Aminobenzenesulfonic acid (0), pK_2	4.075	4.002	3.932	3.865	3.799	3.738	3.679	3.622	3.567	3.464
4-Aminobenzenesulfonic acid (0), pK_2	3.521	3.457	3.398	3.338	3.283	3.227	3.176	3.126	3.079	2.989
3-Aminobenzoic acid (0)					4.90	4.79	4.75		4.68	4.60
4-Aminobenzoic acid (0)					4.95	4.85	4.90		4.95	5.10
2-Aminobutyric acid										
(+1)			2.334			2.286		$2.289^{37.5°C}$		2.297
(0)			10.530			9.380		$9.518^{37.5°C}$		9.234
4-Aminobutyric acid										
(+1)			4.057	4.046	4.038	4.031	4.027	4.025	4.027	4.032
(0)			11.026	10.867	10.706	10.556	10.409	10.269	10.114	9.874
2-Aminoethylsulfonic acid (0)			9.452	9.316	9.186	9.061	8.940	8.824	8.712	9.499

TABLE 8.9 Selected Equilibrium Constants in Aqueous Solution at Various Temperatures (*Continued*)

Substance	Temperature, °C									
	0	5	10	15	20	25	30	35	40	50
2-Amino-3-methylpentanoic acid										
(+1)	$2.365^{1°C}$		$2.338^{12.5°C}$			2.320		$2.317^{37.5°C}$		2.332
(0)	$10.460^{1°C}$		$10.100^{12.5°C}$			9.758		$9.439^{37.5°C}$		9.157
2-Amino-2-methyl-1,3-propanediol	9.612	9.433	9.266	9.104	8.951	8.801	8.659	8.519	8.385	8.132
2-Amino-2-methylpropionic acid										
(+1)	$2.419^{1°C}$		$2.380^{12.5°C}$			2.357		$2.351^{37.5°C}$		2.356
(0)	$10.960^{1°C}$		$10.580^{12.5°C}$			10.205		$9.872^{37.5°C}$		9.561
2-Aminopentanoic acid										
(+1)	$2.376^{1°C}$		2.347			2.318			2.309	2.313
(0)	$10.508^{1°C}$			$10.154^{12.5°C}$		9.808		$9.490^{37.5°C}$		9.198
3-Aminopropionic acid										
(+1)	3.656	3.627		3.583		3.551		3.524	3.517	
(0)	11.000	10.830		10.526		10.235		9.963	9.842	
4-Aminopyridine (+1)	9.873	9.704	9.549	9.398	9.252	9.114	8.978	8.846	8.717	8.477
Ammonium ion (+1)	10.081	9.904	9.731	9.564	9.400	9.245	9.093	8.947	8.805	8.539
Arginine										
(+1)	1.914	1.885	1.870	1.849	1.837	1.823	1.814	1.801	1.800	1.787
(0)	9.718	9.563	9.407	9.270	9.123	8.994	8.859	8.739	8.614	8.385
Barbituric acid										
(+1)				3.969	3.980	4.02	4.00	4.008	4.017	4.032
(0)				8.493	8.435	8.372	8.302	8.227	8.147	7.974
Benzoic acid (0)		4.231	4.220	4.215	4.206	4.204	4.203	4.207	4.219	4.223
Boric acid (0)	9.508	9.439	9.380	9.327	9.280	9.236	9.197	9.161	9.132	9.080
Bromoacetic acid (0)				2.875	2.887	2.902	2.918	2.936		
3-Bromobenzoic acid (0)				3.818	3.813	3.810	3.808	3.810	3.813	
4-Bromobenzoic acid (0)				4.011	4.005	3.99	4.001	4.001	4.003	
Bromopropynoic acid (0)			1.786	1.814	1.839	1.855	1.879	1.900	1.919	

3-*tert*-Butylbenzoic acid (0)				4.266	4.231	4.199	4.170	4.143	4.119	
4-*tert*-Butylbenzoic acid (0)				4.463	4.425	4.389	4.354	4.320	4.287	
2-Butynoic acid (0)			2.618	2.626	2.611	2.620	2.618	2.621	2.631	
Butyric acid (0)	4.806	4.804	4.803	4.805	4.810	4.817	4.827	4.840	4.854	4.885
DL-*N*-Carbamoylalanine (+1)		3.898	3.894	3.891	3.890	3.892	3.896	3.902	3.908	3.931
N-Carbamoylglycine (+1)		3.911	3.900	3.889	3.879	3.876	3.874	3.873	3.875	3.888
Carbon dioxide + water										
(0)	6.577	6.517	6.465	6.429	6.382	6.352	6.327	6.309	6.296	6.285
(−1)	10.627	10.558	10.499	10.431	10.377	10.329	10.290	10.250	10.220	10.172
Chloroacetic acid (0)				2.845	2.856	2.867	2.883	2.900		
3-Chlorobenzoic acid (0)				3.838	3.831	3.83	3.825	3.826	3.829	
4-Chlorobenzoic acid (0)				4.000	3.991	3.986	3.981	3.980	3.981	
Chloropropynoic acid (0)			1.766	1.796	1.820	1.845	1.864	1.879	1.893	
Citric acid										
(0)	3.220	3.200	3.176	3.160	3.142	3.128	3.116	3.109	3.099	3.095
(−1)	4.837	4.813	4.797	4.782	4.769	4.761	4.755	4.751	4.750	4.757
(−2)	6.393	6.386	6.383	6.384	6.388	6.396	6.406	6.423	6.439	6.484
Cyanoacetic acid (0)		2.445	2.447	2.452	2.460	2.460	2.482	2.496	2.511	
2-Cyano-2-methylpropionic acid										
(0)		2.342	2.360	2.379	2.400	2.422	2.446	2.471	2.498	
5,5-Diethylbarbituric acid (0)	8.40	8.30	8.22	8.169	8.094	8.020	7.948	7.877	7.808	7.673
Diethylmalonic acid										
(0)			2.129	2.136	2.144	2.151	2.160	2.172	2.187	
(−1)			7.400	7.401	7.408	7.417	7.428	7.441	7.457	
2,3-Dimethylbenzoic acid (0)				3.663	3.687	3.771	3.726	3.762	3.788	
2,4-Dimethylbenzoic acid (0)				4.154	4.187	4.217	4.244	4.268	4.290	
2,5-Dimethylbenzoic acid (0)				3.911	3.954	3.990	4.020	4.045	4.065	
2,6-Dimethylbenzoic acid (0)				3.234	3.304	3.362	3.409	3.445	3.472	
3,5-Dimethylbenzoic acid (0)				4.292	4.299	4.302	4.304	4.306	4.306	
N,*N*′-Dimethylethyleneamine-*N*,*N*′-diacetic acid										
(0)	6.294		6.169		6.047		5.926		5.803	
(−1)	10.446		10.268		10.068		9.882		9.684	
N,*N*-Dimethylglycine (0)		10.34		10.14		9.94		9.76		
3,5-Dinitrobenzoic acid (0)			2.60		2.73		2.85		2.96	3.07

TABLE 8.9 Selected Equilibrium Constants in Aqueous Solution at Various Temperatures (*Continued*)

Substance	Temperature, °C									
	0	5	10	15	20	25	30	35	40	50
2-Ethylbutyric acid (0)	4.623		4.664		4.710	4.751	4.758		4.812	4.869
5-Ethyl-5-phenylbarbituric acid (0)				7.592	7.517	7.445	7.377	7.311	7.248	7.130
Fluoroacetic acid (0)				2.555	2.571	2.586	2.604	2.624		
Formic acid (0)	3.786	3.772	3.762	3.757	3.753	3.751	3.752	3.758	3.766	3.782
2-Furancarboxylic acid (0)						3.164	3.200	3.216	3.239	
Glucose-1-phosphate (0)		6.506	6.500	6.499	6.500	6.504	6.510	6.519	6.531	6.561
Glycerol-1-phosphoric acid (−1)		6.642	6.641	6.643	6.648	6.656	6.666	6.679	6.695	6.733
Glycerol-2-phosphoric acid										
(0)		1.223	1.245	1.271	1.301	1.335	1.372	1.413	1.457	1.554
(−1)		6.657	6.650	6.646	6.646	6.650	6.657	6.666	6.679	6.712
Glycine										
(+1)			2.397	2.380	2.36	2.351	2.34	2.33	2.327	2.32
(0)		10.34	10.193	10.044	9.91	9.780	9.65	9.53	9.412	9.19
Glycolic acid (0)	3.875		$3.844^{12.5°C}$			3.831		$3.833^{37.5°C}$		3.849
Glycylasparagine (+1)		2.968	2.958	2.952	2.943	2.942	2.942	2.944	2.947	2.959
N-Glycylglycine (+1)	3.201					3.126				3.159
			$8.594^{12.5°C}$			8.252		$7.948^{37.5°C}$		7.668
Hexanoic acid (0)	4.840		4.839		4.849		4.865		4.890	4.920
Hydrogen cyanide (0)			9.63	9.49	9.36	9.21	9.11	8.99	8.88	
Hydrogen peroxide (0)	12.23			11.86	11.75	11.65	11.55	11.45		11.21
Hydrogen sulfide										
(0)		7.33	7.24	7.13	7.05	6.97	6.90	6.82	6.79	6.69
(−1)		13.5		13.2		12.90	12.75	12.6		
4-Hydroxybenzoic acid (0)				4.596	4.586	4.582	4.577	4.576	4.578	
Hydroxylamine (0)				6.186	6.063	5.948		5.730		
2-Hydroxy-1-naphthoic acid										
(0)					3.29		3.24		3.19	3.26
(−1)					9.68		9.65		9.61	9.58

4-Hydroxyproline										
(+1)	1.900[1°C]		1.850[12.5°C]			1.818		1.798[37.5°C]		1.796
(0)	10.274[1°C]		9.958[12.5°C]			9.662		9.394[37.5°C]		9.138
2-Hydroxypropionic acid (0)	3.880	3.873	3.868	3.861	3.857	3.858	3.861	3.867	3.873	3.895
DL-2-Hydroxysuccinic acid										
(0)	3.537	3.520	3.494	3.482	3.472	3.458	3.452	3.446	3.444	3.445
(−1)	5.119	5.108	5.098	5.096	5.096	5.097	5.099	5.104	5.117	5.149
Hypobromous acid (0)				8.83		8.60		8.47	8.37[45°C]	
Hypochlorous acid (0)	7.82	7.75	7.69	7.63	7.58	7.54	7.50	7.46		7.05
Imidazole (+1)	7.581	7.467	7.334	7.216	7.103	6.993	6.887	6.784	6.685	6.497
Iodoacetic acid (0)				3.143	3.158	3.175	3.193	3.213		
DL-Isoleucine										
(+1)	2.365		2.338[12.5°C]			2.318		2.317[37.5°C]		2.332
(0)	10.460		10.100[12.5°C]			9.758		9.439[37.5°C]		9.157
Isopropylmalonic acid, mononitrile (0)		2.299	2.320	2.343	2.365	2.401	2.427	2.452	2.481	
Lactic acid (0)	3.880	3.873	3.868	3.862	3.857	3.858	3.861	3.867	3.873	3.895
Lead sulfate, pK_{sp}	8.01			7.87		7.80		7.73		7.63
DL-Leucine										
(+1)	2.383[1°C]		2.348[12.5°C]			2.328		2.327[37.5°C]		2.333
(0)	10.458[1°C]		10.095[1.5°C]			9.744		9.434[37.5°C]		9.142
Malonic acid (−1)	5.670	5.665	5.667	5.673	5.683	5.696	5.710	5.730	5.753	5.803
Mannose (0)			12.45			12.08			11.81	
Mercury(I) chloride, pK_{sp}			18.65	18.48	18.27	17.88		16.79		
Methanol (solvent), pK_{auto}		17.12		16.84		16.71	16.65	16.53		
Methylamine (+1)	11.496		11.130		10.787	10.62	10.466		10.161	9.876
Methylaminodiacetic acid										
(0)	2.138		2.142		2.146		2.150		2.154	
(−1)	10.474		10.287		10.088		9.920		9.763	
3-Methylbenzoic acid (0)				4.303	4.285	4.269	4.256	4.244	4.235	
4-Methylbenzoic acid (0)				4.390	4.376	4.362	4.349	4.336	4.322	
3-Methylbutyric acid (0)	4.726		4.742		4.767		4.794		4.831	4.871
4-Methylpentanoic acid (0)	4.827		4.827		4.837		4.853		4.879	4.908

TABLE 8.9 Selected Equilibrium Constants in Aqueous Solution at Various Temperatures (*Continued*)

Substance	Temperature, °C									
	0	5	10	15	20	25	30	35	40	50
5-Methyl-5-phenylbarbituric acid										
(0)				8.104	8.057	8.011	7.966	7.922	7.879	7.797
2-Methylpropionic acid (0)	4.825		4.827		4.840	4.853	4.886		4.918	4.955
2-Methyl-2-propylamine (+1)		11.439	11.240	11.048	10.862	10.682	10.511	10.341		
Nitric acid (0)	−1.65					−1.38				−1.20
Nitrilotriacetic acid										
(0)	1.69		1.65		1.65		1.66		1.67	
(−1)	2.95		2.95		2.94		2.96		2.98	
(−2)	10.59		10.45		10.33		10.23			
4-Nitrobenzoic acid (0)				3.448	3.444	3.441	3.441	3.442	3.445	
Nitrous acid (0)				3.244	3.177	3.138		3.100		
DL-Norleucine										
(+1)	2.394		$2.356^{12.5°C}$			2.335		$2.324^{37.5°C}$		2.328
(0)	10.564		$10.190^{12.5°C}$			9.834		$9.513^{37.5°C}$		9.224
Oxalic acid (−1)	4.210	4.216	4.227	4.240	4.254	4.272	4.295	4.318	4.349	4.409
2,4-Pentanedione (0)	9.07					8.95			8.90	
Pentanoic acid (0)	4.823		4.763		4.835	4.842	4.851		4.861	4.906
Phenylalanine (0)			9.75			9.31			8.96	
Phosphoric acid (0)	2.056	2.073	2.088	2.107	2.127	2.148	2.171	2.196	2.224	2.277
(−1)	7.313	7.282	7.254	7.231	7.213	7.198	7.189	7.185	7.181	7.183
o-Phthalic acid										
(0)	2.925	2.927	2.931	2.937	2.943	2.950	2.958	2.967	2.978	3.001
(−1)	5.432	5.418	5.410	5.405	5.405	5.408	5.416	5.427	5.442	5.485
Piperidine (+1)	11.963	11.786	11.613	11.443	11.280	11.123	10.974	10.818	10.670	10.384
Proline										
(+1)	2.011		$1.964^{12.5°C}$			1.952		$1.950^{37.5°C}$		1.958
(0)	11.296		$10.972^{12.5°C}$			10.640		$10.342^{37.5°C}$		10.064
Propenoic acid (0)				4.267	4.250	4.247	4.249	4.267	4.301	

N-Propionylglycine (+1)		3.728	3.723	3.718	3.716	3.718	3.721	3.725	3.731	3.750
Propynoic acid (0)			1.791	1.829	1.867	1.887	1.940	1.932	1.963	
Pyrrolidine (+1)	12.17	11.98	11.81	11.63	11.43	11.30	11.15	10.99	10.84	11.56
Serine										
(+1)	2.296[1°C]		2.232[12.5°C]			2.186		2.154[37.5°C]		2.132
(0)	9.880[1°C]		9.542[12.5°C]			9.208		8.904[37.5°C]		8.628
Silver bromide, pK_{sp}		13.33		12.83	12.57	12.30	12.07	11.83	11.61	11.19
Silver chloride, pK_{sp}		10.595		10.152		9.749		9.381	9.21	8.88
Succinic acid										
(0)	4.285	4.263	4.245	4.232	4.218	4.207	4.198	4.191	4.188	4.186
(−1)	5.674	5.660	5.649	5.642	5.639	5.635	6.541	5.647	5.654	5.680
Sulfuric acid (−1)	1.778	1.812[4.3°C]		1.894		1.987	2.05	2.095	2.17	2.246
Sulfurous acid (0)	1.63		1.74			1.89		1.98		2.12
D-Tartaric acid										
(0)	3.118	3.095	3.075	3.057	3.044	3.036	3.025	3.019	3.018	3.021
(−1)	4.426	4.407	4.391	4.381	4.372	4.366	4.365	4.367	4.372	4.391
2,3,5,6-Tetramethylbenzoic acid				3.310	3.367	3.415	3.453	3.483	3.505	
(0)										
Threonine										
(+1)	2.200[1°C]		2.132[12.5°C]			2.088		2.070[37.5°C]		2.055
(0)	9.748[1°C]		9.420[12.5°C]			9.100		8.812[37.5°C]		8.548
o-Toluidine (0)				4.58	4.495	4.45	4.345	4.28	4.20	
1,2,4-Triazole										
(+1)				2.451	2.418	2.386	2.327			
(0)				10.205	10.083	9.972	9.768			
3,4,5-Trihydroxybenzoic acid (0)					4.19		4.30		4.38	4.53
Tris(2-hydroxyethyl)amine (+1)	8.290	8.173	8.067	7.963	7.861	7.762	7.666	7.570	7.477	7.299
2,4,6-Trimethylbenzoic (0)				3.325	3.391	3.448	3.498	3.541	3.577	
3-Trimethylsilylbenzoic acid (0)				4.142	4.116	4.089	4.060	4.029	3.996	
4-Trimethylsilylbenzoic acid (0)				4.270	4.230	4.192	4.155	4.119	4.084	
β-Ureidopropionic acid (0)		4.514	4.505	4.497	4.490	4.487	4.486	4.486	4.488	4.500
DL-Valine										
(+1)	2.320		2.297[12.5°C]			2.296		2.292[37.5°C]		2.310
(0)	10.413		10.064[12.5°C]			9.719		9.405[37.5°C]		9.124

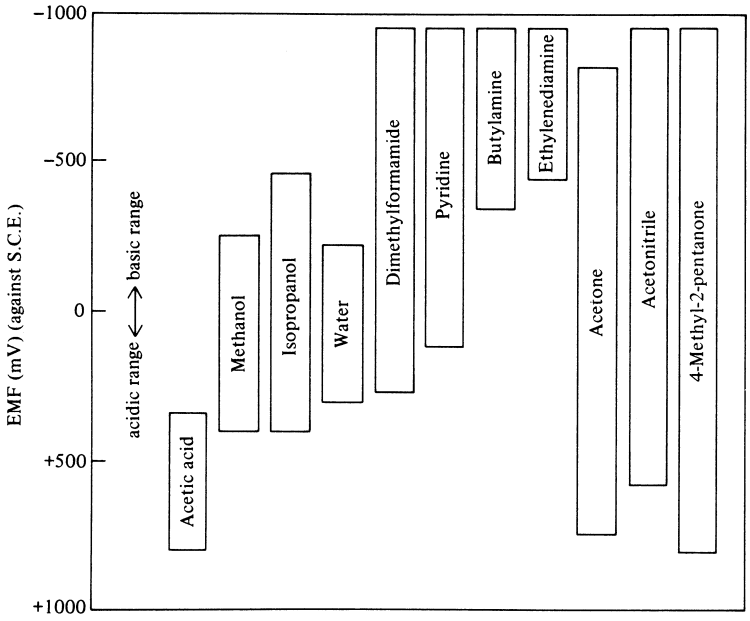

FIGURE 8.1 Approximate potential ranges in nonaqueous solvents.

TABLE 8.10 Properties of Common Acid-Base Solvents

Solvent	Potential Span, mV	$-\log K_s$	Dielectric Constant, 25°C
Acetic acid	400	14.5	6.1(20°)
Acetic anhydride	800	14.5	20.7(20°)
Acetone	1600		20.7
Acetonitrile	1600	26.5	37.5(20°)
Ammonia (at −50°C)		33	22(−33°)
n-Butanol	900		17.1
n-Butylamine	500		4.88(20°)
Chlorobenzene	1500		5.62
N,N-Dimethylformamide	1300	18.0	36.71
Dimethylsulfoxide		17.3	46.6
Ethanol	800	19.1	24.55
Ethanolamine		5.1	37.7
Ethyl acetate	1500		6.02
Ethylenediamine	500	15.3	14.2(20°)
Formic acid	200	6.2	58.5
Methanol	800	16.7	32.7
4-Methyl-2-pentanone (methyl isobutyl ketone)	1600	25.0	13.1(20°)
Nitromethane	1000		35.8(30°)
2-Propanol	900		19.92
Pyridine	1000		12.3
Sulfuric acid		3.85	101
Water	800	14.0	78.3

TABLE 8.11 pK_a Values for Proton-Transfer Reactions in Nonaqueous Solvents

Acid	Methanol	Ethanol	Other Solvents
Acetic acid	9.52	10.32	11.4[a], 9.75[d]
p-Aminobenzoic acid	10.25		
Ammonium ion	10.7		6.40[b]
Anilinium ion	6.0	5.70	
Benzoic acid		10.72	10.0[a]
Bromocresol purple	11.3	11.5	
Bromocresol green	9.8	10.65	
Bromophenol blue	8.9	9.5	
Bromothymol blue	12.4	13.2	
Di-*n*-butylammonium ion			10.3[a]
o-Chloroanilinium ion	3.4		
Cyanoacetic acid		7.49	
2,5-Dichloroanilinium ion			9.48[b]
Dimethylaminoazobenzene		5.2	6.32[b]
N,N′-Dimethylanilinium ion		4.37	
Formic acid		9.15	
Hydrobromic acid			5.5[c]
Hydrochloric acid			8.55[b], 8.9[c]
Methyl orange	3.8	3.4	
Methyl red (acid range)	4.1	3.55	
(alkaline range)	9.2	10.45	
Methyl yellow	3.4	3.55	
Neutral red	8.2	8.2	
o-Nitrobenzoic acid	7.6		
m-Nitrobenzoic acid	8.3		
p-Nitrobenzoic acid	8.4		
Perchloric acid			4.87[b]
Phenol	14.0		
Phenol red	12.8	13.4	
Phthalic acid, pK_2	11.65		11.5[d], 6.10[d](pK_1)
Picric acid	3.8	3.8	8.9[c]
Pyridinium ion			6.1[b]
Salicylic acid	8.7	7.9	
Stearic acid	10.0		
Succinic acid, pK_2	11.4		
Sulfuric acid, pK_1			7.24[b,c]
Tartaric acid, pK_2	9.9		
Thymol blue (alkaline range)	14.0	15.2	
(acid range)	4.7	5.35	
Thymolbenzein (acid range)	3.5		
(alkaline range)	13.1		
p-Toluenesulfonic acid			8.44[b]
p-Toluidinium ion		6.24	
Tribenzylammonium ion			5.40[b]
Tropeoline 00	2.2		
Urea (protonated cation)			6.96[b]
Veronal	12.6		

[a] Dimethylsulfoxide. [b] Glacial acetic acid. [c] Acetonitrile. [d] Acetone + 10% water.

8.2.2 Formation Constants of Metal Complexes

Each value listed in Tables 8.12 and 8.13 is the logarithm of the overall formation constant for the cumulative binding of a ligand L to the central metal cation M, viz.:

	Cumulative formation constant	Stepwise stability constants
$M + L = ML$	K_1	k_1
$M + 2L = ML_2$	K_2	$k_1 k_2$
.....		
$M + nL = ML_n$	K_n	$k_1 k_2 \cdots k_n$

As an example, the entries in Table 8.12 for the zinc ammine complexes represent these equilibria:

$$Zn^{2+} + NH_3 = Zn(NH_3)^{2+} \qquad K_1 = \frac{[Zn(NH_3)^{2+}]}{[Zn^{2+}][NH_3]}$$

$$Zn^{2+} + 2NH_3 = Zn(NH_3)_2^{2+} \qquad K_2 = \frac{[Zn(NH_3)_2^{2+}]}{[Zn^{2+}][NH_3]^2}$$

$$Zn^{2+} + 3NH_3 = Zn(NH_3)_3^{2+} \qquad K_3 = \frac{[Zn(NH_3)_3^{2+}]}{[Zn^{2+}][NH_3]^3}$$

$$Zn^{2+} + 4NH_3 = Zn(NH_3)_4^{2+} \qquad K_4 = \frac{[Zn(NH_3)_4^{2+}]}{[Zn^{2+}][NH_3]^4}$$

If the stepwise stability or formation constants of the reactions are desired, for the first step $\log K_1 = \log k_1 = 2.37$. For the second and succeeding steps the equilibria and corresponding constants are as follows:

$$Zn(NH_3)^{2+} + NH_3 = Zn(NH_3)_2^{2+} \qquad \log k_2 = \log K_2 - \log K_1 = 2.44$$

$$Zn(NH_3)_2^{2+} + NH_3 = Zn(NH_3)_3^{2+} \qquad \log k_3 = \log K_3 - \log K_2 = 3.50$$

$$Zn(NH_3)_3^{2+} + NH_3 = Zn(NH_3)_4^{2+} \qquad \log k_4 = \log K_4 - \log K_3 = 2.15$$

The reverse of the association or formation reactions would represent the dissociation or instability constant for the systems, i.e., $-\log K_f = \log K_{\text{instab}}$.

The data in the tables generally refer to temperatures of about 20 to 25°C. Most of the values in Table 8.12 refer to zero ionic strength, but those in Table 8.13 often refer to a finite ionic strength.

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Ammonia						
Cadmium	2.65	4.75	6.19	7.12	6.80	5.14
Cobalt(II)	2.11	3.74	4.79	5.55	5.73	5.11
Cobalt(III)	6.7	14.0	20.1	25.7	30.8	35.2
Copper(I)	5.93	10.86				
Copper(II)	4.31	7.98	11.02	13.32	12.86	
Iron(II)	1.4	2.2				
Manganese(II)	0.8	1.3				
Mercury(II)	8.8	17.5	18.5	19.28		
Nickel	2.80	5.04	6.77	7.96	8.71	8.74
Platinum(II)						35.3
Silver(I)	3.24	7.05				
Zinc	2.37	4.81	7.31	9.46		
Bromide						
Astatine	2.51 [AtBr]					
Bismuth(III)	4.30	5.55	5.89	7.82		9.70
Bromine	1.24 [Br_3^-]					
Cadmium	1.75	2.34	3.32	3.70		
Cerium(III)	0.42					
Copper(I)		5.89				
Copper(II)	0.30					
Gold(I)		12.46				
Indium	1.30	1.88	2.48			
Iodine	2.64 [IBr]					
Iron(III)	−0.30	−0.50				
Lead	1.2	1.9		1.1		
Mercury(II)	9.05	17.32	19.74	21.00		
Palladium(II)				13.1		
Platinum(II)				20.5		
Rhodium(III)		14.3	16.3	17.6	18.4	17.2
Scandium	2.08	3.08				
Silver(I)	4.38	7.33	8.00	8.73		
Thallium(I)	0.93					
Thallium(III)	9.7	16.6	21.2	23.9	29.2	31.6
Tin(II)	1.11	1.81	1.46			
Uranium(IV)	0.18					
Yttrium	1.32					
Chloride						
Americium(III)	1.17					
Antimony(III)	2.26	3.49	4.18	4.72		
Bismuth(III)	2.44	4.7	5.0	5.6		
Cadmium	1.95	2.50	2.60	2.80		
Cerium(III)	0.48					
Copper(I)		5.5	5.7			
Copper(II)	0.1	−0.6				
Curium(III)	1.17					
Gold(III)		9.8				
Indium	1.42	2.23	3.23			
Iron(II)	0.36					
Iron(III)	1.48	2.13	1.99	0.01		
Lead	1.62	2.44	1.70	1.60		
Manganese(II)	0.96					
Mercury(II)	6.74	13.22	14.07	15.07		

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4	log K_5	log K_6
Palladium(II)	6.1	10.7	13.1	15.7		
Platinum(II)		11.5	14.5	16.0		
Plutonium(III)	1.17					
Silver(I)	3.04	5.04		5.30		
Thallium(I)	0.52					
Thallium(III)	8.14	13.60	15.78	18.00		
Thorium	1.38	0.38				
Tin(II)	1.51	2.24	2.03	1.48		
Tin(IV)						4
Uranium(IV)	0.8					
Uranium(VI)	0.22					
Zinc	0.43	0.61	0.53	0.20		
Zirconium	0.9	1.3	1.5	1.2		
Cyanide						
Cadmium	5.48	10.60	15.23	18.78		
Copper(I)		24.0	28.59	30.30		
Gold(I)		38.3				
Iron(II)						35
Iron(III)						42
Mercury(II)				41.4		
Nickel				31.3		
Silver(I)		21.1	21.7	20.6		
Zinc				16.7		
Fluoride						
Aluminum	6.10	11.15	15.00	17.75	19.37	19.84
Beryllium	5.1	8.8	12.6			
Cerium(III)	3.20					
Chromium(III)	4.41	7.81	10.29			
Gadolinium	3.46					
Gallium	5.08					
Indium	3.70	6.25	8.60	9.70		
Iron(III)	5.28	9.30	12.06			
Lanthanum	2.77					
Magnesium	1.30					
Manganese(II)	5.48					
Plutonium(III)	6.77					
Scandium						17.3
Thallium(I)	0.1					
Thallium(III) [TlO^+]	6.44					
Thorium	7.65	13.46	17.97			
Titanium(IV) [TiO^{2+}]	5.4	9.8	13.7	18.0		
Uranium(VI)	4.59	7.93	10.47	11.84		
Yttrium	4.81	8.54	12.14			
Zirconium	8.80	16.12	21.94			
Hydroxide						
Aluminum	9.27			33.03		
Antimony(III)		24.3	36.7	38.3		
Arsenic [as AsO^+]	14.33	18.73	20.60	21.20		
Beryllium	9.7	14.0	15.2			
Bismuth(III)	12.7	15.8		35.2		
Cadmium	4.17	8.33	9.02	8.62		
Cerium(III)	14.6					
Cerium(IV)	13.28	26.46				

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4	log K_5	log K_6
Chromium(III)	10.1	17.8		29.9		
Copper(II)	7.0	13.68	17.00	18.5		
Dysprosium	5.2					
Erbium(III)	5.4					
Gadolinium	4.6					
Gallium	11.0	21.7		34.3	38.0	40.3
Indium	9.9	19.8		28.7		
Iodine	9.49	11.24				
Iron(II)	5.56	9.77	9.67	8.58		
Iron(III)	11.87	21.17	29.67			
Lanthanum	3.3					
Lead(II)	7.82	10.85	14.58			61.0
Lutetium	6.6					
Magnesium	2.58					
Manganese(II)	3.90		8.3			
Neodymium	5.5					
Nickel	4.97	8.55	11.33			
Praseodymium	4.30					
Plutonium(III)	7.0					
Plutonium(IV)	12.39					
Plutonium [as PuO_2^{2+}]	8.3	16.6	20.9			
Samarium(III)	4.8					
Scandium	8.9					
Tellurium(IV)			41.6	53.0	64.8	72.0
Thallium(III)	12.86	25.37				
Titanium(III)	12.71					
Uranium(IV)	13.3				41.2	
Uranium(VI) [as UO_2^{2+}]	9.5	22.80		32.4		
Vanadium(III)	11.1	21.6				
Vanadium(IV) [as VO^{2+}]	8.6		[25.8 for $V_2O_4(OH)^-$]			
Vanadium(V) [as VO^{3+}]		25.2		46.2	58.5	
Yttrium	5.0					
Zinc	4.40	11.30	14.14	17.66		
Zirconium	14.3	28.3	41.9	55.3		
Iodide						
Bismuth	3.63			14.95	16.80	18.80
Cadmium	2.10	3.43	4.49	5.41		
Copper(I)		8.85				
Indium	1.00	2.26				
Iodine	2.89	5.79				
Iron(III)	1.88					
Lead	2.00	3.15	3.92	4.47		
Mercury(II)	12.87	23.82	27.60	29.83		
Silver	6.58	11.74	13.68			
Thallium(I)	0.72	0.90	1.08			
Thallium(III)	11.41	20.88	27.60	31.82		
Iodate						
Barium	1.05					
Calcium	0.89					
Magnesium	0.72					
Strontium	1.00					
Thorium	2.88	4.79	7.15			

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4	log K_5	log K_6
Nitrate						
Barium	0.92					
Beryllium	1.62					
Bismuth(III)	1.26					
Cadmium	0.40					
Calcium	0.28					
Cerium(III)	1.04	2.55				
Curium(III)	0.57					
Hafnium	0.92	2.43	4.32	6.40	8.48	10.29
Iron(III)	1.0					
Lanthanum	0.26	0.69	1.27			
Lead	1.18					
Mercury(II)	0.35					
Neodymium	0.52	1.18				
Neptunium(IV)	0.38					
Plutonium(III)	0.77	1.93	3.09			
Plutonium(IV)	0.54					
Strontium	0.82					
Thallium(I)	0.33					
Thallium(III)	0.92					
Thorium	0.78	1.89	2.89	3.63		
Uranium(IV)	0.20	0.37				
Uranium(VI)	0.34	0.45				
Ytterbium	0.45	1.30	2.42			
Zirconium [as ZrO^{2+}]		1.91		3.54		
Pyrophosphate						
Barium	4.6					
Calcium	4.6					
Cadmium	5.6					
Copper(II)	6.7	9.0				
Lead		5.3				
Magnesium	5.7					
Nickel	5.8	7.4				
Strontium	4.7					
Yttrium		9.7				
Zirconium		6.5				
Sulfate						
Cerium(III)	3.40					
Erbium	3.58					
Gadolinium	3.66					
Holmium	3.58					
Indium	1.78	1.88	2.36			
Iron(III)	2.03	2.98				
Lanthanum	3.64					
Neodymium	3.64					
Nickel	2.4					
Plutonium(IV)	3.66					
Praseodymium	3.62					
Samarium	3.66					
Thorium	3.32	5.50				
Uranium(IV)	3.24	5.42				
Uranium(VI)	1.70	2.45	3.30			

TABLE 8.12 Cumulative Formation Constants for Metal Complexes with Inorganic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Yttrium	3.47					
Ytterbium	3.58					
Zirconium	3.79	6.64	7.77			
Sulfite						
Copper(I)	7.5	8.5	9.2			
Mercury(II)		22.66				
Silver	5.30	7.35				
Thiocyanate						
Bismuth	1.15	2.26	3.41	4.23		
Cadmium	1.39	1.98	2.58	3.6		
Chromium(III)	1.87	2.98				
Cobalt(II)	−0.04	−0.70	0	3.00		
Copper(I)	12.11	5.18				
Gold(I)		23		42		
Indium	2.58	3.00	4.63			
Iron(III)	2.95	3.36				
Mercury(II)		17.47		21.23		
Nickel	1.18	1.64	1.81			
Ruthenium(III)	1.78					
Silver		7.57	9.08	10.08		
Thallium(I)	0.80					
Uranium(IV)	1.49	2.11				
Uranium(VI)	0.76	0.74	1.18			
Vanadium(III)	2.0					
Vanadium(IV)	0.92					
Zinc	1.62					
Thiosulfate						
Cadmium	3.92	6.44				
Copper(I)	10.27	12.22	13.84			
Iron(III)	2.10					
Lead		5.13	6.35			
Mercury(II)		29.44	31.90	33.24		
Silver	8.82	13.46				

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands

Temperature is 25°C and ionic strengths are approaching zero unless indicated otherwise: (*a*) At 20°C, (*b*) at 30°C, (*c*) 0.1 *M* uni-univalent salt, (*d*) 1.0 *M* uni-univalent salt, (*e*) 2.0 *M* uni-univalent salt present.

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Acetate				
Ag(I)	0.73	0.64		
Ba(II)	0.41			
Ca(II)	0.6			
Cd(II)	1.5	2.3	2.4	
Ce(III)	1.68	2.69	3.13	3.18
Co(II)	1.5	1.9		
Cr(III)	1.80	4.72		
Cu(II) *a*	2.16	3.20		
Fe(II) *c*	3.2	6.1	8.3	
Fe(III) *a,d*	3.2			
In(III)	3.50	5.95	7.90	9.08
Hg(II)		8.43		
La(III) *a,e*	1.56	2.48	2.98	2.95
Mg(II)	0.8			
Mn(II)	9.84	2.06		
Ni(II)	1.12	1.81		
Pb(II)	2.52	4.0	6.4	8.5
Rare earths *a,e*	1.6–1.9	2.8–3.0	3.3–3.7	
Sr(II)	0.44			
Tl(III)				15.4
UO_2(II) *a,e*	2.38	4.36	6.34	
Y(III) *a,e*	1.53	2.65	3.38	
Zn(II)	1.5			
Acetylacetone				
Al(III) *b*	8.6	15.5		
Be(II)	7.8	14.5		
Cd(II)	3.84	6.66		
Ce(III)	5.30	9.27	12.65	
Cr(II)	5.9	11.7		
Co(II)	5.40	9.54		
Cu(II)	8.27	16.34		
Dy(III) *b*	6.03	10.70	14.04	
Er(III) *b*	5.99	10.67	14.09	
Eu(III) *b*	5.87	10.35	13.64	
Fe(II)	5.07	8.67		
Fe(III)	11.4	22.1	26.7	
Ga(III)	9.5	17.9	23.6	
Gd(III) *b*	5.90	10.38	13.79	
Hf(IV)	8.7	15.4	21.8	28.1
Ho(III)	6.05	10.73	14.13	
In(III)	8.0	15.1		
La(III) *b*	5.1	8.90	11.90	
Lu(III) *b*	6.23	11.00	13.63	
Mg(II)	3.65	6.27		
Mn(II)	4.24	7.35		
Mn(III)			3.86	
Nd(III)	5.6	9.9	13.1	
Ni(II) *a*	6.06	10.77	13.09	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Pd(II) *b*	16.2	27.1		
Pr(III) *b*	5.4	9.5	12.5	
Pu(IV) *c*	10.5	19.7	28.1	34.1
Sc(III) *b*	8.0	15.2		
Sm(III) *b*	5.9	10.4		
Tb(III) *b*	6.02	10.63	14.04	
Th(IV)	8.8	16.2	22.5	26.7
Tm(IV) *b*	6.09	10.85	14.33	
U(IV) *a,c*	8.6	17.0	23.4	29.5
UO_2(II) *b*	7.74	14.19		
VO(II)	8.68	15.79		
V(II)	5.4	10.2	14.7	
Y(III) *b*	6.4	11.1	13.9	
Yb(III) *b*	6.18	11.04	13.64	
Zn(II) *b*	4.98	8.81		
Zr(IV)	8.4	16.0	23.2	30.1
Alizarin red				
Cr(VI)	4.7			
Cu(II)	4.1			
Hf(IV)		10.4		
Mo(VI)		9.6		
Pb(II)	6.0			
Th(IV)		8.24		
UO_2(II)	4.22			
V(V)		8.6		
W(VI)		7.8		
Arsenazo				
Hf(IV)	10.07			
Zr(IV)	12.95			
Aurintricarboxylic acid				
Be(II)	4.54			
Cu(II)	4.1	8.81		
Fe(III)	4.68			
Th(IV)	5.04			
UO_2(II)	4.77			
Benzoylacetone (75% dioxane)				
Ba(II)		9.4		
Be(II)	12.59	24.01		
Cd(II)	7.79	14.36		
Ce(III)	10.09	19.42	27.04	
Co(II)	9.42	17.83		
Cu(II)	12.05	23.01		
La(III)	6.33	11.66	16.78	
Mg(II)	7.69	14.09		
Mn(II)	8.66	15.78		
Ni(II)	9.58	18.00		
Pb(II)	8.84	16.35		
Pr(III)	7.02	13.62	18.74	
UO_2(II)	12.15	23.27		
Y(III)	8.24	14.98	20.57	
Zn(II)	9.62	17.90		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Calmagite				
Ca	6.05			
Mg	8.05			

	Complex of HL^{2-} Anion		Complex of L^{3-} Anion		Complex of H_2L^-
	log K_1	log K_2	log K_1	log K_2	log K_3
Citric acid					
Ag	7.1				
Al	7.0		20.0		
Ba	2.98				
Be	4.52				
Ca	4.68				
Cd	3.98		11.3		
Ce(III)		6.18		9.65	3.2
Co(II)	4.8		12.5		
Cu(II)	4.35		14.2		
Eu(III)		6.46		9.80	
Fe(II)	3.08		15.5		
Fe(III)	12.5		25.0		
La		6.97		9.45	6.22
Mg	3.29				
Mn(II)	3.67				
Nd(III)		6.32		9.70	
Ni	5.11		14.3		
Pb	6.50				
Pr					3.4
Ra	2.36				
Sr	2.8				
Tl(I)	1.04				
UO_2	8.5	10.8			
Y					3.6
Yb				8	
Zn	4.71		11.4		

	log K_1	log K_2	log K_3	
1,2-Diaminocyclohexane-*N,N,N′,N′*-tetraacetic acid				
Al *c*	17.63			
Ba *c*	8.64			
Ca *c*	12.3			
Cd *c*	19.88			
Ce(III) *c*	16.76			
Co(II) *c*	19.57			
Cu(II) *c*	21.95			
Dy(III) *c*	19.69			
Er(III) *c*	20.20			
Eu(III) *c*	18.77			
Fe(III) *c*	27.48			
Ga *c*	22.91			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Gd *c*	18.80			
Hg(II) *c*	24.4			
Ho *c*	19.89			
La *c*	16.35			
Lu *c*	21.51			
Mg *c*	10.41			
Mn(II) *c*	17.43			
Nd *c*	17.69			
Ni *c*	19.4			
Pb *c*	20.33			
Pr *c*	17.23			
Sm(III) *c*	18.63			
Sr *c*	8.92			
Tb *c*	19.30			
Tm *c*	20.46			
VO(II) *c*	19.40			
Y *c*	19.41			
Yb *c*	20.80			
Zn *c*	18.6			
Dibenzoylmethane (75% dioxane)				
Ba	6.10	11.50		
Be	13.62	26.03		
Ca	7.17	13.55		
Cd	8.67	16.63		
Ce(III)	10.99	21.53	30.38	
Co(II)	10.35	20.05		
Cu(II)	12.98	24.98		
Cs	3.42			
Fe(II)	11.15	21.50		
K	3.67			
Li	5.95			
Mg	8.54	16.21		
Mn(II)	9.32	17.79		
Na	4.18			
Ni	10.83	20.72		
Pb	9.75	18.79		
Rb	3.52			
Sr	6.40	12.10		
Zn	10.23	19.65		

	log K_1	log K_2	log K_3	log K_f [MHL]
4,5-Dihydroxybenzene-1,3-disulfonic acid (Tiron)				
Al	19.02	31.10	33.5	
Ba	4.10			14.6
Ca	5.80			14.8
Cd *d*	7.69	13.29		
Ce(III)		3.75		
Co(II) *d*	8.19	14.41		15.7
Cu(II) *d*	12.76	23.73		18.1

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_f [MHL]
Fe(III) *a,c*	20.7	35.9	46.9	22.6
La	12.9			18.6 [La(OH)L]
Mg *a,c*	6.86			14.6
Mn(II) *c*	8.6			
Ni *a,c*	8.56	14.90		15.6
Pb *d*	11.95	18.28		
Sr *c*	4.55			
UO_2(II) *c*	15.90			
VO(II)	15.88			
Zn *d*	9.00	16.91		15.9

	log K_1	log K_2	log K_f [M_2L_3]
2,3-Dimercaptopropan-1-of (BAL)			
Fe(II)	15.8		
Fe(III)	30.6 [Fe(OH)L]		28
Mn(II)	5.23	10.43	
Ni		22.78	
Zn	13.48	23.3	40.6

	log K_1	log K_2	log K_3	log K_4
Dimethylglyoxime (50% dioxane)				
Cd	5.7	10.7		
Co(II)	9.80	18.94		
Cu(II)	12.00	33.44		
Fe(II)		7.25		
La	6.6	12.5		
Ni	11.16			
Pb	7.3			
Zn	7.7	13.9		
2,2′-Dipyridyl				
Ag	3.65	7.15		
Cd	4.26	7.81	10.47	
Co(II)	5.73	11.57	17.59	
Cr(II)	4.5	10.5	14.0	
Cu(I)		14.2		
Cu(II)	8.0	13.60	17.08	
Fe(II)	4.36	8.0	17.45	
Hg(II)	9.64	16.74	19.54	
Mg	0.5			
Mn(II) *d*	4.06	7.84	11.47	
Ni	6.80	13.26	18.46	
Pb	3.0			
Ti(III)			25.28	
V(II)	4.9	9.6	13.1	
Zn	5.30	9.83	13.63	
Eriochrome Black T				
Ca	5.4			
Mg	7.0			
Zn	13.5	20.6		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Ethanolamine				
Ag	3.29	6.92		
Cu(II)		6.68		16.48
Hg(II)	8.51	17.32		
Ethylenediamine				
Ag	4.70	7.70		
Cd *a*	5.47	10.09	12.09	
Co(II)	5.91	10.64	13.94	
Co(III)	18.7	34.9	48.69	
Cr(II)	5.15	9.19		
Cu(I)		10.8		
Cu(II)	10.67	20.00	21.0	
Fe(II)	4.34	7.65	9.70	
Hg(II)	14.3	23.3		
Mg	0.37			
Mn(II)	2.73	4.79	5.67	
Ni	7.52	13.84	18.33	
Pd(II)		26.90		
V(II)	4.6	7.5	8.8	
Zn	5.77	10.83	14.11	
Ethylenediamine-*N, N, N′, N′*-tetraacetic acid				
Ag	7.32			
Al	16.11			
Am(III)	18.18			
Ba	7.78			
Be	9.3			
Bi	22.8			
Ca	11.0			
Cd	16.4			
Ce(III)	16.80			
Cf(III)	19.09			
Cm(III)	18.45			
Co(II)	16.31			
Co(III)	36			
Cr(II)	13.6			
Cr(III)	23			
Cu(II)	18.7			
Dy	18.0			
Er	18.15			
Eu(III)	17.99			
Fe(II)	14.33			
Fe(III)	24.23			
Ga	20.25			
Gd	17.2			
Hg(II)	21.80			
Ho	18.1			
In	24.95			
La	16.34			
Li	2.79			
Lu	19.83			
Mg	8.64			
Mn(II)	13.8			
Mo(V)	6.36			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Na	1.66			
Nd	16.6			
Ni	18.56			
Pb	18.3			
Pd(II)	18.5			
Pm(III)	17.45			
Pr	16.55			
Pu(III)	18.12			
Pu(IV)	17.66			
Pu(VI)	17.66			
Ra	7.4			
Sc	23.1			
Sm	16.43			
Sn(II)	22.1			
Sr	8.80			
Tb	17.6			
Th	23.2			
Ti(III)	21.3			
TiO(II)	17.3			
Tl(III)	22.5			
Tm	19.49			
U(IV)	17.50			
V(II)	12.70			
V(III)	25.9			
VO(II)	18.0			
V(V)	18.05			
Y	18.32			
Yb	18.70			
Zn	16.4			
Zr	19.40			
Glycine				
Ag	3.41	6.89		
Ba	0.77			
Be		4.95		
Ca	1.38			
Cd	4.74	8.60		
Co(II)	5.23	9.25	10.76	
Cu(II)	8.60	15.54	16.27	
Dy		12.2		
Er		12.7		
Fe(II) *a*	4.3	7.8		
Fe(III) *a,d*	10.0			
Gd		11.9		
Hg(II)	10.3	19.2		
La		11.2		
Mg	3.44	6.46		
Mn(II)	3.6	6.6		
Ni	6.18	11.14	15	
Pb	5.47	8.92		
Pd(II)	9.12	17.55		
Pr		11.5		
Sm		11.7		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Sr	0.91			
Y		12.5		
Yb		13.0		
Zn	5.52	9.96		
***N′*-(2-Hydroxyethyl)ethylenediamine-*N*, *N*, *N′*-triacetic acid**				
Ba *c*	5.54			
Ca *c*	8.43			
Cd *c*	13.0			
Ce(III) *c*	14.11			
Co(II) *c*	14.4			
Cu(II) *c*	17.40			
Dy *c*	15.30			
Er *c*	15.42			
Eu(III) *c*	15.35			
Fe(II) *c*	11.6			
Fe(III) *c*	19.8			
Gd *c*	15.22			
Hg(II) *c*	20.1			
Ho *c*	15.32			
La *c*	13.46			
Lu *c*	15.88			
Mg *c*	5.78			
Mn(II) *c*	10.7			
Nd *c*	14.86			
Ni *c*	17.0			
Pb *c*	15.5			
Pr *c*	14.61			
Sm *c*	15.28			
Sr *c*	6.92			
Tb *c*	15.32			
Th *c*	18.5			
Tm *c*	15.59			
Y *c*	14.65			
Yb *c*	15.88			
Zn *c*	14.5			
8-Hydroxy-2-methylquinoline (50% dioxane)				
Cd	9.00	9.00	16.60	
Ce(III)	7.71			
Co(II)	9.63	18.50		
Cu(II)	12.48	24.00		
Fe(II)	8.75	17.10		
Mg	5.24	9.64		
Mn(II)	7.44	13.99		
Ni	9.41	17.76		
Pb	10.30	18.50		
UO_2(II)	9.4	17		
Zn	9.82	18.72		
8-Hydroxyquinoline-5-sulfonic acid				
Ba	2.31			
Ca	3.52			
Cd	7.70	14.20		
Ce(III)	6.05	11.05	14.95	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Co(II)	8.11	15.05	20.41	
Cu(II)	11.92	21.87		
Er	7.16	13.34	18.56	
Fe(II)	8.4	15.7	21.75	
Fe(III)	11.6	22.8	35.65	
Gd	6.64	12.37	17.27	
La	5.63	10.13	13.83	
Mg	4.79	8.19		
Mn(II)	5.67	10.72		
Nd	6.3	11.6	16.0	
Ni	9.57	18.27	22.9	
Pb	8.53	16.13		
Pr	6.17	11.37	15.67	
Sm	6.58	12.28	17.04	
Sr	2.75			
Th	9.56	18.29	25.92	32.04
UO_2(II)	8.52	15.67		
Zn	8.65	16.15		
Lactic acid				
Ba	0.64			
Ca	1.42			
Cd	1.70			
Ce(III) *a,c*	2.76	4.73	5.96	
Co(II)	1.90			
Cu(II)	3.02	4.85		
Er	2.77	5.11	6.70	
Eu(III)	2.53	4.60	5.88	
Fe(III)	7.1			
Gd	2.53	4.63	5.91	
Ho	2.71	4.97	6.55	
La *a,c*	2.60	4.34	5.64	
Li	0.20			
Mg	1.37			
Mn(II)	1.43			
Nd	2.47	4.37	5.60	
Ni	2.22			
Pb	2.40	3.80		
Pr *a,c*	2.85	4.90	6.10	
Rare earths *a,c*	2.8–3.0	4.9–5.4	6.1–7.8	
Sm	2.56	4.58	5.90	
Sr	0.98			
Tb	2.61	4.73	6.01	
Y	2.53	4.70	6.12	
Yb	2.85	5.27	7.96	
Zn	2.20	3.75		
Nitrilotriacetic acid				
Al	>10			
Ba *a*	5.88			
Ca	7.60	11.61		
Cd *c*	9.80	15.2		
Ce(III) *c*	10.83	18.67		

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Co(II) *c*	10.38	14.5		
Cr(III)	>10			
Cu(II) *c*	13.10			
Dy *c*	11.74	21.15		
Er *c*	12.03	21.29		
Eu(III) *c*	11.52	20.70		
Fe(II) *c*	8.84			
Fe(III) *c*	15.87	24.32		
Gd *c*	11.54	20.80		
Hg(II)	12.7			
Ho *c*	11.90	21.25		
In	15			
La *c*	10.36	17.60		
Li *a*	3.28			
Lu *c*	12.49	21.91		
Mg *c*	5.36	10.2		
Mn(II)	8.60	11.1		
Na	2.15			
Nd *c*	11.26	19.73		
Ni	11.26	16.0		
Pb *a,c*	11.8			
Pr *c*	11.07	19.25		
Sm(III) *c*	11.53	20.53		
Sr	6.73			
Tb *c*	11.59	20.97		
Tl(I)	3.44			
Th *c*	12.4			
Tm *c*	12.22	21.45		
Y *c*	11.48	20.43		
Yb *c*	12.40	21.69		
Zn *c*	10.45	13.45		
Zr *c*	20.8			
1-Nitroso-2-naphthol (75% dioxane)				
Ag	7.74			
Cd	6.18	11.38		
Co(II)	10.67	22.81		
Cu(II)	12.52	23.37		
Mg	6.2	10.60		
Nd	9.5	17.7	25.6	
Ni	10.75	21.29	28.09	
Pb	9.73	17.31		
Pr	9.04	17.06	23.85	
Th *c*	8.50	16.13	24.03	30.29
Y	9.02	17.74	25.04	
Zn	9.32	17.02		
Zr	3.6			
Oxalate				
Ag	2.41			
Al	7.26	13.0	16.3	
Am(III)		9.8		$[Am(HL)_4^-$ 11.0]
Ba	2.31			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Be	4.90			
Ca	3.0			
Cd	3.52	5.77		
Ce(III)	6.52	10.5	11.3	
Co(II)	4.79	6.7	9.7	
Co(III)			~20	
Cu(II)	6.16	8.5		
Er	4.82	8.21	10.03	
Fe(II)	2.9	4.52	5.22	
Fe(III)	9.4	16.2	20.2	
Gd	7.04			
Hg(II)		6.98		
Mg	3.43	4.38		
Mn(II)	3.97	5.80		
Mn(III) *e*	9.98	16.57	19.42	
Mo(III)	3.38			
Mo(VI)				$[MoO_3(L)^{2-}$ 13.0]
Nd	7.21	11.5	>14	
Ni	5.3	7.64	~8.5	
NpO_2(II)	3.30	7.07		
Pb		6.54		
Pu(III)	9.31	18.70	28	
Pu(IV)	8.74	16.91	23.39	27.50
PuO_2(II)		11.4		
Sr	2.54			
Th				24.48
TiO(II)	2.67			
Tl(I)	2.03			
UO_2(II)		10.57		
VO(II)		9.80		
V(II)	~2.7			
Y	6.52	10.10	11.47	
Yb	7.30	11.7	>14	
Zn	4.89	7.60	8.15	
Zr	9.80	17.14	20.86	21.15
1,10-Phenanthroline				
Ag	5.02	12.07		
Ca	0.7			
Cd	5.93	10.53	14.31	
Co(II)	7.25	13.95	19.90	
Cu(II)	9.08	15.76	20.94	
Fe(II)	5.85	11.45	21.3	
Fe(III)	6.5	11.4	23.5	
Hg(II)		19.65	23.35	
Mg	1.2			
Mn(II)	3.88	7.04	10.11	
Ni	8.80	17.10	24.80	
Pb	4.65	7.5	9	
VO(II)	5.47	9.69		
Zn	6.55	12.35	17.55	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
Phthalic acid				
Ba	2.33			
Ca	2.43			
Cd	2.5			
Co(II)	1.81	4.51		
Cu(II)	3.46	4.83		
La		7.74		
Ni	2.14			
Pb *d*	3.4			
UO_2(II)	4.38			
Zn	2.2			
Piperidine				
Ag	3.30	6.48		
Hg(II)	8.70	17.44		
Pt(II)			log K_5 5.7	log K_6 8.2
Propylene-1,2-diamine				
Cd *b,c*		9.97	12.12	
Co(II) *d*	5.42	11.47	14.72	
Cu(II) *c*	6.41	20.06		
Hg(II) *c*	10.78	23.53	23.25	
Ni *d*	7.43	13.62	17.89	
Zn *b,c*	5.89	10.87	12.57	
Pyridine				
Ag	1.97	4.35		
Cd	1.40	1.95	2.27	2.50
Co(II)	1.14	1.54		
Cu(I)		3.34	4.51	5.44
				log K_6 6.89
Cu(II)	2.59	4.33	5.93	6.54
			log K_5 7.00	log K_6 10.2
Fe(II)	0.71			
Hg(II)	5.1	10.0	10.4	
Mn(II)	1.92	2.77	3.37	3.50
VO(II)	−1.70			
Zn	1.41	1.11	1.61	1.93
Pyridine-2,6-dicarboxylic acid				
Ba *a,d*	3.46			
Ca *a,d*	4.6	7.2		
Cd *a,d*	5.7	10.0		
Ce(III) *a,d*	8.34	14.42	18.80	
Co(II) *a,d*	7.0	12.5		
Cu(II) *a,d*	9.14	16.52		
Dy *a,d*	8.69	16.19	22.14	
Er *a,d*	8.77	16.39	22.14	
Eu(III) *a,d*	8.84	15.98	21.00	
Fe(II) *a,d*	5.71	10.36		
Fe(III) *a,d*	10.91	17.13		
Gd *a,d*	8.74	16.06	21.83	
Ho *a,d*	8.72	16.23	22.08	
La *a,d*	7.98	13.79	18.06	
Lu *a,d*	9.03	16.80	21.48	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Hg(II) *a,d*	20.28			
Mg *a,d*	2.7			
Mn(II) *a,d*	5.01	8.49		
Nd *a,d*	8.78	15.60	20.66	
Ni *a,d*	6.95	13.50		
Pb *a,d*	8.70	10.60		
Pr *a,d*	8.63	15.10	19.94	
Sm *a,d*	8.86	15.88	21.23	
Sr *a,d*	3.89			
Tb *a,d*	8.68	16.11	22.03	
Tm *a,d*	8.83	16.54	22.04	
Y *a,d*	8.46	15.73	21.34	
Yb *a,d*	8.85	16.61	21.83	
Zn *a,d*	6.35	11.88		
1-(2-Pyridylazo)-2-naphthol (PAN)				
Co(II)	>12			
Cu(II)	16			
Mn(II)	8.5	16.4		
Ni	12.7	25.3		
Tl(III)	2.29			
Zn	11.2	21.7		

	$\log K_f$ [ML]	$\log K_f$ [MHL]	$\log K_f$ [M(HL)$_2$]
4-(2-Pyridylazo)resorcinal (PAR)			
Co(II)		>12	
Cu(II)	10.3		
Mn(II)		9.7	18.9
Ni		13.2	26.0
Sc	4.8		
Tl(III)	4.23		
Zn		12.4	23.5

	$\log K_f$ [ML]	$\log K_f$ [M$_2$L]	$\log K_f$ [MHL]
Pyrocatechol-3,5-disulfonate (Pyrocatechol Violet)			
Al	19.13	4.95	
Bi	27.07	5.25	
Cd	8.13		5.86
Co(II)	9.01		6.53
Cu(II)	16.47		11.18
Ga	22.18	4.65	
In	18.10	4.81	
Mg	4.42	4.6	3.66
Mn(II)	7.13		5.36
Ni	9.35	4.38	6.85
Pb	13.25		10.19
Th	23.36	4.42	
Zn	10.41	6.21	7.21
Zr	27.40	4.18	

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	log K_1	log K_2	log K_3	log K_4
8-Quinolinol				
Ba	2.07			
Be	3.36			
Ca (75% dioxane)	7.3	13.2		
Cd	7.2	13.4		
Ce(III) (50% dioxane)	9.15	17.13		
Co(II)	9.1	17.2		
Cu(II)	12.2	23.4		
Fe(II)	8.58	16.93	22.23	
Fe(III)	12.3	23.6	33.9	
La	5.85	16.95		
Mg (50% dioxane)	6.38	11.81		
Mn(II) (50% dioxane)	8.28	15.45		
Ni (50% dioxane)	11.44	21.38		
Pb (50% dioxane)	10.61	18.70		
Sm	6.84		19.50	
Sr	2.89	6.08		
Th	10.45	20.40	29.85	38.80
UO_2(II) (50% dioxane)	11.25	20.89		
V(II)	12.8	23.6		
VO(II)	10.97	20.19		
Y	8.15	14.90	20.25	
Zn (50% dioxane)	9.96	18.86		

	log K_f [MHL^+]	log K_f [$M(HL)_2$]
Salicylaldoxime		
Ba	0.53	3.72
Be	<7	
Ca	0.92	3.72
Cd	<4.4	
Co(II)		8.13
Cu(II)		8.13
Mg	0.64	4.10
Ni		3.77
Sr		3.77
Zn	<5.2	

	log K_1	log K_2	log K_3	log K_4
Salicylic acid				
Al	14.11			
Be	17.4			
Cd	5.55			
Ce(III)	2.66			
Co(II)	6.72	11.42		
Cr(II)	8.4	15.3		
Cu(II)	10.60	18.45		
Fe(II)	6.55	11.25		
Fe(III) *a,c*	16.48	28.12	36.80	
La	2.64			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Mg (75% dioxane)	4.7			
Mn(II)	5.90	9.80		
Nd	2.70			
Ni	6.95	11.75		
Pr	2.68			
Th	4.25	7.60	10.05	11.60
TiO(II)	6.09			
UO_2(II)	13.4			
V(II)	6.3			
Zn	6.85			
Succinic acid				
Ba	2.08			
Be	3.08			
Ca	2.0			
Cd	2.2			
Co(II)	2.22			
Cu(II)	3.33			
Fe(III)	7.49			
Hg(II)		7.28		
La	3.96			
Mg	1.20			
Mn(II)	2.26			
Nd	8.1			
Ni	2.36			
Pb	2.8			
Ra	1.0			
Sr	1.06			
Zn	1.6			
5-Sulfosalicylic acid				
Al *c*	13.20	22.83	28.89	
Be *c*	11.71	20.81		
Cd *c*	16.68	29.08		
Co(II) *c*	6.13	9.82		
Cr(II) *c*	7.1	12.9		
Cr(III) *c*	9.56			
Cu(II) *c*	9.52	16.45		
Fe(II) *c*	5.90			
Fe(III) *c*	14.64	25.18	32.12	
La *c*	9.11			
Mn(II) *c*	5.24	8.24		
NbO(III) *c*	4.0	7.7		
Ni *c*	6.42	10.24		
UO_2(II) *c*	11.14	19.20		
Zn *c*	6.05	10.65		
Tartaric acid				
Ba		1.62		
Bi			8.30	
Ca	2.98	9.01		
Cd	2.8			
Co(II)	2.1			
Cu(II)	3.2	5.11	4.78	6.51 $\log K_f$ 19.14 $[Cu(OH)_2L^{2-}]$

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
Eu(III)	4.98	8.11		
Fe(III)	7.49			
La	3.06			
Mg		1.36		
Nd	9.0			
Pb	3.78		4.7	log K_f 14.1 $[Pb(OH)_2L^{2-}]$
Ra	1.24			
Sr	1.60			
Zn	2.68	8.32		
Thioglycolic acid				
Ce(III) *a,c*	1.99	3.03		
Co(II)	5.84	12.15		
Fe(II)		10.92		
Hg(II)		43.82		
La *a,c*	1.98	2.98		
Mn(II)	4.38	7.56		
Pb	8.5			
Ni	6.98	13.53		
Rare earths *a,c*	1.9–2.1	3.0–3.3		
Y *a,c*	1.91	3.19		
Zn	7.86	15.04		
Thiourea				
Ag	7.4	13.1		
Bi				log K_6 11.9
Cd	0.6	1.6	2.6	4.6
Cu(I)			13	15.4
Hg(II)		22.1	24.7	26.8
Pb	1.4	3.1	4.7	8.3
Ru(III)	1.21		0.72	
Thoron				
Th		10.15		
Triethanolamine				
Ag	2.30	3.64		
Co(II)	1.73			
Cu(II)	4.30			
Hg(II)	6.90	13.08		
Ni	2.7			
Zn	2.00			
Triethylenetetramine (Trien)				
Ag	7.7			
Cd	10.75	13.9		
Co(II)	11.0			
Cu(II)	20.4			
Fe(II)	7.8			
Fe(III)	21.9			
Hg(II)	25.26			
Mn(II)	4.9			
Ni	14.0			
Pb	10.4			
Zn	11.9			

TABLE 8.13 Cumulative Formation Constants for Metal Complexes with Organic Ligands (*Continued*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
1,1,1-Trifluoro-3-2′-Thenoylacetone (TTA)				
Ba		10.6		
Cu(II)	6.55	13.0		
Fe(III)	6.9			
Ni	10.0			
Pr	9.53			
Pu(III)	9.53			
Pu(IV)	8.0			
Th	8.1			
U(IV)	7.2			
Zr	3.03 [as ZrL^{3+}]			
Xylenol orange				
Bi	5.52			
Fe(III)	5.70			
Hf	6.50			
Tl(III)	4.90			
Zn	6.15			
Zr	7.60			
Zincon				
Zn	13.1			

8.3 BUFFER SOLUTIONS

8.3.1 Standard Reference pH Buffer Solutions

The assigned values of pH_s, according to the Bates-Guggenheim convention [*Pure Applied Chem.* **1:**163 (1960)], for the primary standard solutions prepared from salts issued by the National Institute for Science and Technology (NIST, US) (U.S.) are given in Table 8.14. These are smoothed values. The ionic strength of these reference solutions is 0.1 or less. Strictly speaking the NIST scale uses a molality concentration system; however, values are given in molarity units for convenience.

As a result of a variable liquid-junction potential, the measured pH may be expected to differ seriously from the pa_H determined from cells without a liquid junction in solutions of high acidity or high alkalinity. Merely to affirm the proper functioning of the glass electrode at the extreme ends of the pH scale, two secondary standards are included in Table 8.14. In addition, values for a 0.1 *m* solution of HCl are given to extend the pH scale up to 275°C [see R. S. Greeley, *Anal. Chem.* **32:**1717 (1960)]:

t, °C:	25	60	90	125	150	175	200	225–275
pH:	1.10	1.11	1.12	1.13	1.14	1.15	1.16	1.2

Uncertainties in the values are ±0.03 pH unit from 25 to 90°C, ±0.05 pH unit from 125 to 200°C, and ±0.1 pH unit from 225 to 275°C.

TABLE 8.14 National Bureau of Standards (U.S.) Reference pH Buffer Solutions

Temperature °C	Secondary standard 0.05 *M* K tetraoxalate	KH tartrate (saturated at 25°C)	0.05 *M* KH_2 citrate	0.05 *M* KH phthalate	0.025 *M* KH_2PO_4, 0.025 *M* Na_2HPO_4	0.0087 *M* KH_2PO_4, 0.0302 *M* Na_2HPO_4	0.01 *M* $Na_2B_4O_7$	0.025 *M* $NaHCO_3$, 0.025 *M* Na_2CO_3	Secondary standard $Ca(OH)_2$ (saturated at 25°C)
0	1.666		3.860	4.003	6.984	7.534	9.464	10.317	13.423
5	1.668		3.840	3.999	6.951	7.500	9.395	10.245	13.207
10	1.638		3.820	3.997	6.923	7.472	9.332	10.179	13.003
15	1.642		3.802	3.998	6.900	7.448	9.276	10.118	12.810
20	1.644		3.788	4.002	6.881	7.429	9.225	10.062	12.627
25	1.646	3.557	3.776	4.005	6.865	7.413	9.180	10.012	12.454
30	1.648	3.552	3.766	4.011	6.853	7.400	9.139	9.966	12.289
35		3.549	3.759	4.018	6.844	7.389	9.102	9.925	12.133
38	1.649	3.548	3.756	4.030	6.840	7.384	9.088	9.910	12.043
40	1.650	3.547	3.753	4.035	6.838	7.380	9.068	9.889	11.984
45		3.547		4.047	6.834	7.373	9.038		11.841
50	1.653	3.549	3.749	4.050	6.833	7.367	9.011	9.828	11.705
55		3.554		4.075	6.834		8.985		11.574
60	1.660	3.560		4.081	6.836		8.962		11.449
70	1.671	3.580		4.116	6.845		8.921		
80	1.689	3.609		4.164	6.859		8.885		
90	1.72	3.650		4.205	6.877		8.850		
95	1.73	3.674		4.227	6.886		8.833		
Dilution value $\Delta pH_{1/2}$	+0.186	+0.049	0.024	+0.052	+0.080	+0.070	+0.01	0.079	−0.28

Source: R. G. Bates, *J. Res. Natl. Bur. Stand. (U.S.),* **66A:**179 (1962) and B. R. Staples and R. G. Bates, *J. Res. Natl. Bur. Stand. (U.S.),* **73A:**37 (1969).

Note: The uncertainty is ±0.003 in pH in the range 0–50°C, rising to ±0.02 above 70°C.

TABLE 8.15 Compositions of Standard pH Buffer Solutions [National Bureau of Standards (U.S.)]
Air weight of material per liter of buffer solution.

Standard	Weight, g
$KH_3(C_2O_4)_2 \cdot 2H_2O$, 0.05*M*	12.61
Potassium hydrogen tartrate, about 0.034*M*	Saturated at 25°C
Potassium hydrogen phthalate, 0.05*M*	10.12
Phosphate:	
KH_2PO_4, 0.025*M*	3.39
Na_2HPO_4, 0.025*M*	3.53
Phosphate:	
KH_2PO_4, 0.008665*M*	1.179
Na_2HPO_4, 0.03032*M*	4.30
$Na_2B_4O_7 \cdot 10H_2O$, 0.01*M*	3.80
Carbonate:	
$NaHCO_3$, 0.025*M*	2.10
Na_2CO_3, 0.025*M*	2.65
$Ca(OH)_2$, about 0.0203*M*	Saturated at 25°C

The buffer values for the NBS reference pH buffer solutions are given below:

Buffer solution	KH tartrate	0.05 *M* KH_2 citrate	0.05 *M* KH phthalate	0.025 *M* KH_2PO_4, 0.25 *M* Na_2HPO_4	0.0087 *M* KH_2PO_4, 0.0302 *M* Na_2HPO_4	0.01 *M* $Na_2B_4O_7$	0.025 *M* $NaHCO_3$, 0.025 *M* Na_2CO_3
Buffer value β	0.027	0.034	0.016	0.029	0.016	0.020	0.029

For the secondary pH reference standards, the buffer value is 0.070 for potassium tetroxalate and 0.09 for calcium hydroxide.

To prepare the standard pH buffer solutions recommended by the National Bureau of Standards (U.S.), the indicated weights of the pure materials in Table 8.15 should be dissolved in water of specific conductivity not greater than 5 micromhos. The tartrate, phthalate, and phosphates can be dried for 2 h at 100°C before use. Potassium tetroxalate and calcium hydroxide need not be dried. Fresh-looking crystals of borax should be used. Before use, excess solid potassium hydrogen tartrate and calcium hydroxide must be removed. Buffer solutions pH 6 or above should be stored in plastic containers and should be protected from carbon doxide with soda-lime traps. The solutions should be replaced within 2 to 3 weeks, or sooner if formation of mold is noticed. A crystal of thymol may be added as a preservative.

8.3.2 Standards for pH Measurement of Blood and Biological Media

Blood is a well-buffered medium. In addition to the NBS phosphate standard of 0.025 *M* (pH_s = 6.480 at 38°C), another reference solution containing the same salts, but in the molal ratio 1:4, has an ionic strength of 0.13. It is prepared by dissolving 1.360 g of KH_2PO_4 and 5.677 g of Na_2HPO_4 (air weights) in carbon dioxide-free water to make 1 liter of solution. The pH_s is 7.416 ± 0.004 at 37.5 and 38°C.

The compositions and pH_s values of *tris*(hydroxymethyl)aminomethane, covering the pH range 7.0 to 8.9, are listed in Table 8.16.

TABLE 8.16 Composition and pH Values of Buffer Solutions

Values based on the conventional activity pH scale as defined by the National Bureau of Standards (U.S.) and pertain to a temperature of 25°C [Ref: Bower and Bates, *J. Research Natl. Bur. Standards (U.S.)*, **55:**197 (1955) and Bates and Bower, *Anal. Chem.*, **28:**1322 (1956)]. Buffer value is denoted by column headed β.

25 ml 0.2*M* KCl + *x* ml 0.2*M* HCl, Diluted to 100 ml			50 ml 0.1*M* KH Phthalate + *x* ml 0.1*M* HCl, Diluted to 100 ml			50 ml 0.1*M* KH Phthalate + *x* ml 0.1*M* NaOH, Diluted to 100 ml		
pH	*x*	β	pH	*x*	β	pH	*x*	β
1.00	67.0	0.31	2.20	49.5		4.20	3.0	0.017
1.20	42.5	0.34	2.40	42.2	0.036	4.40	6.6	0.020
1.40	26.6	0.19	2.60	35.4	0.033	4.60	11.1	0.025
1.60	16.2	0.077	2.80	28.9	0.032	4.80	16.5	0.029
1.80	10.2	0.049	3.00	22.3	0.030	5.00	22.6	0.031
2.00	6.5	0.030	3.20	15.7	0.026	5.20	28.8	0.030
2.20	3.9	0.022	3.40	10.4	0.023	5.40	34.1	0.025
			3.60	6.3	0.018	5.60	38.8	0.020
			3.80	2.9	0.015	5.80	42.3	0.015
50 ml 0.1*M* KH_2PO_4 + *x* ml 0.1*M* NaOH, Diluted to 100 ml			50 ml 0.1*M* *Tris*(hydroxymethyl)aminomethane + *x* ml 0.1*M* HCl, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.028$ $I = 0.001x$			50 ml of a Mixture 0.1*M* with Respect to Both KCl and H_3BO_3 + *x* ml 0.1*M* NaOH, Diluted to 100 ml		
pH	*x*	β	pH	*x*	β	pH	*x*	β
5.80	3.6		7.00	46.6		8.00	3.9	
6.00	5.6	0.010	7.20	44.7	0.012	8.20	6.0	0.011
6.20	8.1	0.015	7.40	42.0	0.015	8.40	8.6	0.015
6.40	11.6	0.021	7.60	38.5	0.018	8.60	11.8	0.018
6.60	16.4	0.027	7.80	34.5	0.023	8.80	15.8	0.022
6.80	22.4	0.033	8.00	29.2	0.029	9.00	20.8	0.027
7.00	29.1	0.031	8.20	22.9	0.031	9.20	26.4	0.029
7.20	34.7	0.025	8.40	17.2	0.026	9.40	32.1	0.027
7.40	39.1	0.020	8.60	12.4	0.022	9.60	36.9	0.022
7.60	42.4	0.013	8.80	8.5	0.016	9.80	40.6	0.016
7.80	44.5	0.009	9.00	5.7		10.00	43.7	0.014
8.00	46.1					10.20	46.2	
50 ml 0.025*M* Borax + *x* ml 0.1*M* HCl, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.008$ $I = 0.025$			50 ml 0.025*M* Borax + *x* ml 0.1*M* NaOH, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.008$ $I = 0.001(25 + x)$			50 ml 0.05*M* $NaHCO_3$ + *x* ml 0.1*M* NaOH, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.009$ $I = 0.001(25 + 2x)$		
pH	*x*	β	pH	*x*	β	pH	*x*	β
8.00	20.5		9.20	0.9		9.60	5.0	
8.20	19.7	0.010	9.40	3.6	0.026	9.80	6.2	0.014
8.40	16.6	0.012	9.60	11.1	0.022	10.00	10.7	0.016
8.60	13.5	0.018	9.80	15.0	0.018	10.20	13.8	0.015
8.80	9.4	0.023	10.00	18.3	0.014	10.40	16.5	0.013

TABLE 8.16 Composition and pH Values of Buffer Solutions (*Continued*)

50 ml 0.025*M* Borax + *x* ml 0.1*M* HCl, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.008$ $I = 0.025$			50 ml 0.025*M* Borax + *x* ml 0.1*M* NaOH, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.008$ $I = 0.001(25 + x)$			50 ml 0.05*M* $NaHCO_3$ + *x* ml 0.1*M* NaOH, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.009$ $I = 0.001(25 + 2x)$		
pH	*x*	β	pH	*x*	β	pH	*x*	β
9.00	4.6	0.026	10.20	20.5	0.009	10.60	19.1	0.012
9.10	2.0		10.40	22.1	0.007	10.80	21.2	0.009
			10.60	23.3	0.005	11.00	22.7	

50 ml 0.05*M* Na_2HPO_4 + *x* ml 0.1*M* NaOH, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.025$ $I = 0.001(77 + 2x)$			25 ml 0.2*M* KCl + *x* ml 0.2*M* NaOH, Diluted to 100 ml $\Delta pH/\Delta t \simeq -0.033$ $I = 0.001(50 + 2x)$		
pH	*x*	β	pH	*x*	β
11.00	4.1	0.009	12.00	6.0	0.028
11.20	6.3	0.012	12.20	10.2	0.048
11.40	9.1	0.017	12.40	16.2	0.076
11.60	13.5	0.026	12.60	25.6	0.12
11.80	19.4	0.034	12.80	41.2	0.21
11.90	23.0	0.037	13.00	66.0	0.30

The phosphate-succinate system gives the values of pH_s shown below:

Molality KH_2PO_4 = Molality $Na_2HC_6H_5O_7$	pH_s	$\Delta(pH_s/\Delta t)$
0.005	6.251	$-0.000\ 86\ deg^{-1}$
0.010	6.197	−0.000 71
0.015	6.162	
0.020	6.131	
0.025	6.109	−0.000 4

TABLE 8.17 Standard Reference Values pH_s^* for the Measurement of Acidity in 50 Weight Percent Methanol-Water

Temperature, °C	0.02*m* HOAc, 0.02*m* NaOAc, 0.02*m* NaCl	0.02*m* NaHSuc, 0.02*m* NaCl	0.02*m* KH_2PO_4, 0.02*m* Na_2HPO_4, 0.02*m* NaCl
10	5.560	5.806	7.937
15	5.549	5.786	7.916
20	5.543	5.770	7.898
25	5.540	5.757	7.884
30	5.540	5.748	7.872
35	5.543	5.743	7.863
40	5.550	5.741	7.858

OAc = acetate Suc = succinate

Reference: R. G. Bates, *Anal Chem.*, **40**(6):35A (1968).

TABLE 8.18 pH* Values for Buffer Solutions in Alcohol-Water Solvents at 25°C

Liquid-junction potential not included.

Solvent Composition (weight per cent alcohol)	0.01*M* $H_2C_2O_4$, 0.01*M* $NH_4HC_2O_4$	0.01*M* H_2Suc, 0.01*M* LiHSuc	0.01*M* HSal, 0.01*M* NaSal
	Methanol-Water Solvents		
0	2.15	4.12	
10	2.19	4.30	
20	2.25	4.48	
30	2.30	4.67	
40	2.38	4.87	
50	2.47	5.07	
60	2.58	5.30	
70	2.76	5.57	
80	3.13	6.01	
90	3.73	6.73	
92	3.90	6.92	
94	4.10	7.13	
96	4.39	7.43	
98	4.84	7.89	
99	5.20	8.23	
100	5.79	8.75	7.53
	Ethanol-Water Solvents		
0	2.15	4.12	
30	2.32	4.70	
50	2.51	5.07	
71.9	2.98	5.71	
100			8.32

Suc = succinate Sal = salicylate

8.3.3 Buffer Solutions Other Than Standards

The range of the buffering effect of a single weak acid group is approximately one pH unit on either side of the pK_a. The ranges of some useful buffer systems are collected in Table 8.19. After all the components have been brought together, the pH of the resulting solution should be determined at the temperature to be employed with reference to standard reference solutions. Buffer components should be compatible with other components in the system under study; this is particularly significant for buffers employed in biological studies. Check tables of formation constants to ascertain whether metal-binding character exists.

TABLE 8.19 pH Values of Biological and Other Buffers for Control Purposes

Materials	Acronym	pK_a	pH range
p-Toluenesulfonate and *p*-toluenesulfonic acid		1.7	1.1–3.3
Glycine and HCl		2.35	1.0–3.7
Citrate and HCl		3.13	1.3–4.7
Formate and HCl		3.71	2.8–4.6
Succinate and borax		4.21, 5.64	3.0–5.8
Phenyl acetate and HCl		4.31	3.5–5.0
Acetate and acetic acid		4.76	3.7–5.6
Succinate and succinic acid		4.21, 5.64	4.8–6.3
2-(*N*-Morpholino)ethanesulfonic acid	MES	6.1	5.5–6.7
Bis(2-hydroxyethyl)iminotris(hydroxymethyl)methane	BIS-TRIS	6.5	5.8–7.2
KH_2PO_4 and borax		2.2, 7.2; 9	5.8–9.2
N-(2-Acetamido)-2-iminodiacetic acid	ADA	6.6	6.0–7.2
2-[(2-Amino-2-oxoethyl)amino]ethanesulfonic acid	ACES	6.8	6.1–7.5
Piperazine-*N*,*N*′-bis(2-ethanesulfonic acid)	PIPES	6.8	6.1–7.5
3-(*N*-Morpholino)-2-hydroxypropanesulfonic acid	MOPSO	6.9	6.2–7.6
1,3-Bis[tris(hydroxymethyl)methylamino]propane	BIS-TRIS PROPANE	6.8, 9.0	6.3–9.5
KH_2PO_4 and Na_2HPO_4		7.2	6.1–7.5
N,*N*-Bis(2-hydroxyethyl)-2-aminoethanesulfonic acid	BES	7.1	6.4–7.8
3-(*N*-Morpholino)propanesulfonic acid	MOPS	7.2	6.5–7.9
N-(2-Hydroxyethyl)piperazine-*N*′-(2-ethanesulfonic acid)	HEPES	7.5	6.8–8.2
N-Tris(hydroxymethyl)methyl-2-aminoethanesulfonic acid	TES	7.5	6.8–8.2
3-[*N*,*N*-Bis(2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid	DIPSO	7.6	7.0–8.2
3-[*N*-tris(hydroxymethyl)methylamino]-2-hydroxypropanesulfonic acid	TAPSO	7.6	7.0–8.2
5,5-Diethylbarbiturate (veronal) and HCl		8.0	7.0–8.5
Tris(hydroxymethyl)aminoethane	TRIZMA	8.1	7.0–9.1
N-(2-hydroxyethyl)piperazine-*N*′-(2-hydroxypropanesulfonic acid)	HEPPSO	7.8	7.1–8.5
Piperazine-*N*,*N*′-bis(2-hydroxypropanesulfonic acid)	POPSO	7.8	7.2–8.5
Triethanolamine	TEA	7.8	6.9–8.5
N-Tris(hydroxymethyl)methylglycine	TRICINE	8.1	7.4–8.8
Borax and HCl			7.6–8.9
N,*N*-Bis(2-hydroxyethyl)glycine	BICINE	8.3	7.6–9.0
N-Tris(hydroxymethyl)methyl-3-aminopropanesulfonic acid	TAPS	8.4	7.7–9.1
3-[(1,1-Dimethyl-2-hydroxyethyl)-2-hydroxypropanesulfonic acid	AMPSO	9.0	8.3–9.7
Ammonia (aqueous) and NH_4Cl		9.2	8.3–9.2
2-(*N*-Cyclohexylamino)-2-hydroxy-1-propanesulfonic acid	CHES	9.3	8.6–10.0

TABLE 8.19 pH Values of Biological and Other Buffers for Control Purposes (*Continued*)

Materials	Acronym	pK_a	pH range
Glycine and NaOH		9.7	8.2–10.1
Ethanolamine (2-aminoethanol) and HCl		9.5	8.6–10.4
3-(Cyclohexylamino)-2-hydroxy-1-propanesulfonic acid	CAPSO	9.6	8.9–10.3
2-Amino-2-methyl-1-propanol	AMP	9.7	9.0–10.5
Carbonate and hydrogen carbonate		10.3	9.2–11.0
Borax and NaOH			9.4–11.1
3-(Cyclohexylamino)-1-propanesulfonic acid	CAPS	10.4	9.7–11.1
Na_2HPO_4 and NaOH		11.9	11.0–12.0

x mL of 0.2*M* Sodium Acetate (27.199 g $NaOAc \cdot 3H_2O$ per liter) plus *y* mL of 0.2*M* Acetic Acid

pH	NaOAc, mL	Acetic Acid, mL
3.60	7.5	92.5
3.80	12.0	88.0
4.00	18.0	82.0
4.20	26.5	73.5
4.40	37.0	63.0
4.60	49.0	51.0
4.80	60.0	40.0
5.00	70.5	29.5
5.20	79.0	21.0
5.40	85.5	14.5
5.60	90.5	9.5

x mL of 0.1*M* KH_2PO_4 (13.617 g $\cdot L^{-1}$) plus *y* mL of 0.05*M* Borax Solution (19.404 g $Na_2B_4O_7 \cdot 10H_2O$ per Liter)

pH	KH_2PO_4, mL	Borax, mL	pH	KH_2PO_4, mL	Borax, mL
5.80	92.1	7.9	7.60	51.7	48.3
6.00	87.7	12.3	7.80	49.2	50.8
6.200	83.0	17.0	8.00	46.5	53.5
6.40	77.8	22.2	8.20	43.0	57.0
6.60	72.2	27.8	8.40	38.7	61.3
6.80	66.7	33.3	8.60	34.0	66.0
7.00	62.3	37.7	8.80	27.6	72.4
7.20	58.1	41.9	9.00	17.5	82.5
7.40	55.0	45.0	9.20	5.0	95.0

x mL of Veronal (20.6 g Na Diethylbarbiturate per Liter) plus *y* mL of 0.1*M* HCl

pH	Veronal, mL	HCl, mL
7.00	53.6	46.4
7.20	55.4	44.6
7.40	58.1	41.9
7.60	61.5	38.5
7.80	66.2	33.8
8.00	71.6	28.4
8.20	76.9	23.1
8.40	82.3	17.7
8.60	87.1	12.9
8.80	90.8	9.2
9.00	93.6	6.4

x mL of 0.2*M* Aqueous NH_3 Solution plus *y* mL of 0.2*M* NH_4Cl (10.699 g $\cdot L^{-1}$)

pH	Aq NH_3, mL	NH_4Cl, mL
8.00	5.5	94.5
8.20	8.5	91.5
8.40	12.5	87.5
8.60	18.5	81.5
8.80	26.0	74.0
9.00	36.0	64.0
9.25	50.0	50.0
9.40	58.5	41.5
9.60	69.0	31.0
9.80	78.0	22.0
10.00	85.0	15.0

x mL of 0.1*M* Citrate (21.0 g Citric Acid Monohydrate + 200 mL 1*M* NaOH per Liter) plus *y* mL of 0.1*M* NaOH

pH	Citrate, mL	NaOH, mL
5.10	90.0	10.0
5.30	80.0	20.0
5.50	71.0	29.0
5.70	67.0	33.0
5.90	62.0	38.0

TABLE 8.19 pH Values of Biological and Other Buffers for Control Purposes (*Continued*)

x mL of 0.2*M* NaOH Added to 100 mL of Stock Solution (0.04*M* Acetic Acid, 0.04*M* H_3PO_4, and 0.04*M* Boric Acid)

pH	NaOH, mL	pH	NaOH, mL	pH	NaOH, mL	pH	NaOH, mL
1.81	0.0	4.10	25.0	6.80	50.0	9.62	75.0
1.89	2.5	4.35	27.5	7.00	52.5	9.91	77.5
1.98	5.0	4.56	30.0	7.24	55.0	10.38	80.0
2.09	7.5	4.78	32.5	7.54	57.5	10.88	82.5
2.21	10.0	5.02	35.0	7.96	60.0	11.20	85.0
2.36	12.5	5.33	37.5	8.36	62.5	11.40	87.5
2.56	15.0	5.72	40.0	8.69	65.0	11.58	90.0
2.87	17.5	6.09	42.5	8.95	67.5	11.70	92.5
3.29	20.0	6.37	45.0	9.15	70.0	11.82	95.0
3.78	22.5	6.59	47.5	9.37	72.5	11.92	97.5

x mL of 0.1*M* HCl plus *y* mL of 0.1*M* Glycine (7.505 g Glycine + 5.85 g NaCl per Liter)			*x* mL of 0.1*M* HCl plus *y* mL of 0.1*M* Citrate (21.008 g Citric Acid Monohydrate + 200 ml 1*M* NaOH per Liter)			*x* mL of 0.05*M* Succinic Acid (5.90 g · L^{-1}) plus *y* mL of Borax Solution (19.404 g $Na_2B_4O_7 \cdot 10H_2O$ per Liter)		
pH	HCl, mL	Glycine, mL	pH	HCl, mL	Citrate, mL	pH	Succinic Acid, mL	Borax, mL
1.20	84.0	16.0	3.50	52.8	47.2	3.60	90.5	9.5
1.40	71.0	29.0	3.60	51.3	48.7	3.80	86.3	13.7
1.60	61.8	38.2	3.80	48.6	51.4	4.00	82.2	17.8
1.80	55.2	44.8	4.00	43.8	56.2	4.20	77.8	22.2
2.00	49.1	50.9	4.20	38.6	61.4	4.40	73.8	26.2
2.20	42.7	57.3	4.40	34.6	65.4	4.60	70.0	30.0
2.40	36.5	63.5	4.60	24.3	75.7	4.80	66.5	33.5
2.60	30.3	69.7	4.80	11.0	89.0	5.00	63.2	36.8
2.80	24.0	76.0				5.20	60.5	39.5
3.00	17.8	82.2				5.40	57.9	42.1
3.30	10.8	89.2				5.60	55.7	44.3
3.60	6.0	94.0				5.80	54.0	46.0

x mL of 0.2*M* $Na_2HPO_4 \cdot 2H_2O$ (35.599 g · L^{-1}) plus *y* mL of 0.1*M* Citric Acid (19.213 g · L^{-1})

pH	Na_2HPO_4, mL	Citric Acid, mL	pH	Na_2HPO_4, mL	Citric Acid, mL	pH	Na_2HPO_4, mL	Citric Acid, mL
2.20	2.00	98.00	4.20	41.40	58.60	6.20	66.10	33.90
2.40	6.20	93.80	4.40	44.10	55.90	6.40	69.25	30.75
2.60	10.90	89.10	4.60	46.75	53.25	6.60	72.75	27.25
2.80	15.85	84.15	4.80	49.30	50.70	6.80	77.25	22.75
3.00	20.55	79.45	5.00	51.50	48.50	7.00	82.35	17.65
3.20	24.70	75.30	5.20	53.60	46.40	7.20	86.95	13.05
3.40	28.50	71.50	5.40	55.75	44.25	7.40	90.85	9.15
3.60	32.20	67.80	5.60	58.00	42.00	7.60	93.65	6.35
3.80	35.50	64.50	5.80	60.45	39.55	7.80	95.75	4.25
4.00	38.55	61.45	6.00	63.15	36.85	8.00	97.25	2.75

When there are two or more acid groups per molecule, or a mixture is composed of several overlapping acids, the useful range is larger. Universal buffer solutions consist of a mixture of acid groups which overlap such that successive pK_a values differ by 2 pH units or less. The Prideaux-Ward mixture comprises phosphate, phenyl acetate, and borate plus HCl and covers the range from 2 to 12 pH units. The McIlvaine buffer is a mixture of citric acid and Na_2HPO_4 that covers the range from pH 2.2 to 8.0. The Britton-Robinson system consists of acetic acid, phosphoric acid, and boric acid plus NaOH and covers the range from pH 4.0 to 11.5. A mixture composed of Na_2CO_3, NaH_2PO_4, citric acid, and 2-amino-2-methyl-1,3-propanediol covers the range from pH 2.2 to 11.0.

General directions for the preparation of buffer solutions of varying pH but fixed ionic strength are given by Bates.* Preparation of McIlvaine buffered solutions at ionic strengths of 0.5 and 1.0 and Britton-Robinson solutions of constant ionic strength have been described by Elving et al.† and Frugoni,‡ respectively.

* Bates, *Determination of pH, Theory and Practice*, Wiley, New York, 1964, pp. 121–122.
† Elving, Markowitz, and Rosenthal, *Anal. Chem.*, **28:**1179 (1956).
‡ Frugoni, *Gazz. Chim. Ital.*, **87:**L403 (1957).

8.4 REFERENCE ELECTRODES

TABLE 8.20 Potentials of Reference Electrodes in Volts as a Function of Temperature

Liquid-junction potential included.

Temp., °C	0.1*M* KCl Calomel*	1.0*M* KCl Calomel*	3.5*M* KCl Calomel*	Satd. KCl Calomel*	1.0*M* KCl Ag/AgCl†	1.0*M* KBr Ag/AgBr‡	1.0*M* KI Ag/AgI§
0	0.3367	0.2883		0.25918	0.23655	0.08128	−0.14637
5					0.23413	0.07961	−0.14719
10	0.3362	0.2868	0.2556	0.25387	0.23142	0.07773	−0.14822
15	0.3361			0.2511	0.22857	0.07572	−0.14942
20	0.3358	0.2844	0.2520	0.24775	0.22557	0.07349	−0.15081
25	0.3356	0.2830	0.2501	0.24453	0.22234	0.07106	−0.15244
30	0.3354	0.2815	0.2481	0.24118	0.21904	0.06856	−0.15405
35	0.3351			0.2376	0.21565	0.06585	−0.15590
38	0.3350		0.2448	0.2355			
40	0.3345	0.2782	0.2439	0.23449	0.21208	0.06310	−0.15788
45					0.20835	0.06012	−0.15998
50	0.3315	0.2745		0.22737	0.20449	0.05704	−0.16219
55					0.20056		
60	0.3248	0.2702		0.2235	0.19649		
70					0.18782		
80				0.2083	0.1787		
90					0.1695	0.0251	

* Bates et al., *J. Research Natl. Bur. Standards*, **45,** 418 (1950).
† Bates and Bower, *J. Research Natl. Bur. Standards*, **53,** 283 (1954).
‡ Hetzer, Robinson and Bates, *J. Phys. Chem.*, **66,** 1423 (1962).
§ Hetzer, Robinson and Bates, *J. Phys. Chem.*, **68,** 1929 (1964).

TABLE 8.20 Potentials of Reference Electrodes in Volts as a Function of Temperature (*Continued*)

Temp., °C	125	150	175	200	225	250	275
1.0*M* KCl Ag/AgCl*	0.1330	0.1032	0.0708	0.0348	−0.0051	−0.054	−0.090
1.0*M* KBr Ag/AgBr†	−0.0048	−0.0312	−0.0612	−0.0951			

* Greeley et al., *J. Phys. Chem.*, **64,** 652 (1960).
† Towns et al., *J. Phys. Chem.*, **64,** 1861 (1960).

The values of several additional reference electrodes at 25°C are listed:

Ag/AgCl, satd. KCl	0.198
Ag/AgCl, 01*M* KCl	0.288
Hg/HgO, 1.0*M* NaOH	0.140
Hg/HgO, 0.1*M* NaOH	0.165
Hg/Hg_2SO_4, satd. K_2SO_4 (22°C)	0.658
Hg/Hg_2SO_4, satd. KCl	0.655

TABLE 8.21 Potentials of Reference Electrodes (in Volts) at 25°C for Water–Organic Solvent Mixtures *Electrolyte solution of* 1*M* HCl.

Solvent, wt %	Methanol, Ag/AgCl	Ethanol, Ag/AgCl	2-Propanol, Ag/AgCl	Acetone, Ag/AgCl	Dioxane, Ag/AgCl	Ethylene glycol, Ag/AgCl	Methanol, calomel	Dioxane, calomel
5			0.2180	0.2190		0.2190		
10	0.2153	0.2146	0.2138	0.2156		0.2160		
20	0.2090	0.2075	0.2063	0.2079	0.2031	0.2101	0.255	0.2501
30		0.2003				0.2036		
40	0.1968	0.1945		0.1859		0.1972	0.243	
45					0.1635			0.2104
50		0.1859		0.158				
60	0.1818	0.173				0.1807		
70		0.158			0.0659		0.216	0.1126
80	0.1492	0.136						
82					−0.0614			−0.0014
90	0.1135	0.096		−0.034				
94.2	0.0841							
98		0.0215						
99							0.103	
100	−0.0099	−0.0081		−0.53				

8.4.1 Electrometric Measurement of pH

The pH value is defined for an aqueous solution in an operational (arbitrary but reproducible) manner according to the Bates-Guggenheim convention:

$$pH_x = pH_s + \frac{E_x - E_s}{2.3026RT/F}$$

where R is the gas constant per mole, T is the temperature on the absolute scale, and F is the faraday. The pH_x of the unknown medium is calculated from that of an accepted standard (pH_s) and the measured difference in the emf (E) of the electrode combination when the standard solution is removed from the cell and replaced by the unknown. The double vertical line marks a liquid junction. Electrodes as fabricated exhibit variations in the reproducibility of the reference electrode, in the liquid-junction potential, and, with glass electrodes, in the asymmetry potential. These differences are all eliminated in the standardizing procedure with standard reference pH buffers. (See R. G. Bates, *Determination of pH, Theory and Practice*, Wiley, New York, 1964.)

Electrode reversible to hydrogen ions	Standard reference buffer or unknown solution	Salt bridge (KCl. 3.5*M* or saturated)	Reference electrode

An electrometric pH-measurement system consists of (1) pH-responsive electrode, (2) reference electrode, and (3) potential-measuring device—some form of high-impedance electronic voltmeter for glass-electrode combinations and this or a potentiometer arrangement for other pH-responsive electrodes. Electronic pH meters are simply voltmeters with scale divisions in pH units which are equivalent to the values of $2.3026RT/F$ (in mV) per pH unit. Values of this function at several temperatures are given in Table 8.22. There is no compensation incorporated in the meter for the changes in pH of the test solution as a function of temperature. Reliability of an indicator–reference electrode combination must be ascertained by standardization of the pH meter with one standard buffer and checking the pH response by immersing the combination in a second and different reference buffer.

The temperature compensator on a pH meter varies the instrument definition of a pH unit from 54.20 mV at 0°C to perhaps 66.10 mV at 60°C. This permits one to measure the pH of the sample (and reference buffer standard) at its actual temperature and thus avoid error due to dissociation equilibria and to junction potentials which have significant temperature coefficients.

TABLE 8.22 Values of $2.3026RT/F$ at Several Temperatures

In millivolts.

t °C	Value	t °C	Value	t °C	Value	t °C	Value
0	54.197	25	59.157	50	64.118	80	70.070
5	55.189	30	60.149	55	65.110	85	71.062
10	56.181	35	61.141	60	66.102	90	72.054
15	57.173	38	61.737	65	67.094	95	73.046
18	57.767	40	62.133	70	68.086	100	74.038
20	58.165	45	63.126	75	69.078		

Report of the National Academy of Sciences: National Research Council Committee of Fundamental Constants, 1963.

8.5 INDICATORS

TABLE 8.23 Indicators for Aqueous Acid-Base Titrations

This table lists some selected indicators. The pH range or transition interval given in the third column may vary appreciably from one observer to another, and, in addition, it is affected by ionic strength, temperature, and illumination; consequently only approximate values can be given. They should be considered to refer to solutions having low ionic strengths and a temperature of about 25°C. In the fourth column the pK_a ($-\log K_a$) of the indicator as determined spectrophotometrically is listed. In the fifth column the wavelength of maximum absorption is given first for the acidic and then for the basic form of the indicator, and the same order is followed in giving the colors in the sixth column. The abbreviations used to describe the colors of the two forms of the indicator are as follows:

B, blue	G, green
V, violet	P, purple
Y, yellow	R, red
O, orange	O-Br, orange-brown
C, colorless	

Indicator	Chemical name	pH range	pK_a	λ_{max}, nm	Color change
Cresol red (acid range)	*o*-Cresolsulfonephthalein	0.2–1.8			R-Y
Cresol purple (acid range)	*m*-Cresolsulfonephthalein	1.2–2.8	1.51	533, —	R-Y
Thymol blue (acid range)	Thymolsulfonephthalein	1.2–2.8	1.65	544, 430	R-Y
Tropeolin OO	Diphenylamino-*p*-benzene sodium sulfonate	1.3–3.2	2.0	527, —	R-Y
2,6-Dinitrophenol	2,6-Dinitrophenol	2.4–4.0	3.69		C-Y
2,4-Dinitrophenol	2,4-Dinitrophenol	2.5–4.3	3.90		C-Y
Methyl yellow	Dimethylaminoazobenzene	2.9–4.0	3.3	508, —	R-Y
Methyl orange	Dimethylaminoazobenzene sodium sulfonate	3.1–4.4	3.40	522, 464	R-O
Bromophenol blue	Tetrabromophenolsulfonephthalein	3.0–4.6	3.85	436, 592	Y-BV
Bromocresol green	Tetrabromo-*m*-cresolsulfonephthalein	4.0–5.6	4.68	444, 617	Y-B
Methyl red	*o*-Carboxybenzeneazodimethylaniline	4.4–6.2	4.95	530, 427	R-Y
Chlorophenol red	Dichlorophenolsulfonephthalein	5.4–6.8	6.0	—, 573	Y-R
Bromocresol purple	Dibromo-*o*-cresolsulfonephthalein	5.2–6.8	6.3	433, 591	Y-P
Bromophenol red	Dibromophenolsulfonephthalein	5.2–6.8		—, 574	Y-R
p-Nitrophenol	*p*-Nitrophenol	5.3–7.6	7.15	320, 405	C-Y
Bromothymol blue	Dibromothymolsulfonephthalein	6.2–7.6	7.1	433, 617	Y-B
Neutral red	Aminodimethylaminotoluphenazonium chloride	6.8–8.0	7.4		R-Y
Phenol red	Phenolsulfonephthalein	6.4–8.0	7.9	433, 558	Y-R
m-Nitrophenol	*m*-Nitrophenol	6.4–8.8	8.3	—, 570	C-Y

TABLE 8.23 Indicators for Aqueous Acid-Base Titrations (*Continued*)

Indicator	Chemical name	pH range	pK_a	λ_{max}, nm	Color change
Cresol red	*o*-Cresolsulfonephthalein	7.2–8.8	8.2	434, 572	Y-R
m-Cresol purple	*m*-Cresolsulfonephthalein	7.6–9.2	8.32	—, 580	Y-P
Thymol blue	Thymolsulfonephthalein	8.0–9.6	8.9	430, 596	Y-B
Phenolphthalein	Phenolphthalein	8.0–10.0	9.4	—, 553	C-R
α-Naphtholbenzein	α-Naphtholbenzein	9.0–11.0			Y-B
Thymolphthalein	Thymolphthalein	9.4–10.6	10.0	—, 598	C-B
Alizarin Yellow R	5-(*p*-Nitrophenylazo)-salicyclic acid, Na salt	10.0–12.0	11.16		Y-V
Tropeolin O	*p*-Sulfobenzenazo-resorcinol	11.0–13.0			Y-O-Br
Nitramine	2,4,6-Trinitrophenyl-methylnitroamine	10.8–13.0			C-O-Br

TABLE 8.24 Mixed Indicators

Mixed indicators give sharp color changes and are especially useful in titrating to a given titration exponent (p*I*).

The information given in this table is from the two-volume work *Volumetric Analysis* by Kolthoff and Stenger, published by Interscience Publishers, Inc., New York, 1942 and 1947, and reproduced with their permission.

Composition of Indicator Solution		p*I*	Color		Notes
			Acid	Alkaline	
1 part 0.1% methyl yellow in alc. 1 part 0.1% methylene blue in alc.	*	3.25	Blue-violet	Green	Still green at pH 3.4, blue-violet at 3.2†
1 part 0.14% xylene cyanol FF in alc. 1 part 0.1% methyl orange in aq.	*	3.8	Violet	Green	Color is gray at pH 3.8
1 part 0.1% methyl orange in aq. 1 part 0.25% indigo carmine in aq.	*	4.1	Violet	Green	Good indicator, especially in artificial light
1 part 0.1% methyl orange in aq. 1 part 0.1% aniline blue in aq.		4.3	Violet	Green	
1 part 0.1% bromcresol green sodium salt in aq. 1 part 0.02% methyl orange in aq.		4.3	Orange	Blue-green	Yellow at pH 3.5, greenish yellow at 4.0, weakly green at 4.3
3 parts 0.1% bromcresol green in alc. 1 part 0.2% methyl red in alc.		5.1	Wine-red	Green	Very sharp color change†
1 part 0.2% methyl red in alc. 1 part 0.1% methylene blue in alc.	*	5.4	Red-violet	Green	Color is red-violet at pH 5.2, a dirty blue at 5.4, and a dirty green at 5.6
1 part 0.1% chlorphenol red sodium salt in aq. 1 part 0.1% aniline blue in water		5.8	Green	Violet	Pale violet at pH 5.8
1 part 0.1% bromcresol green sodium salt in aq. 1 part 0.1% chlorphenol red sodium salt in aq.		6.1	Yellow-green	Blue-violet	Blue-green at pH 5.4, blue at 5.8, blue with a touch of violet at 6.0, blue-violet at 6.2
1 part 0.1% bromcresol purple sodium salt in aq. 1 part 0.1% bromthymol blue sodium salt in aq.		6.7	Yellow	Violet-blue	Yellow-violet at pH 6.2, violet at 6.6, blue-violet at 6.8
2 parts 0.1% bromthymol blue sodium salt in aq. 1 part 0.1% azolitmin in aq.		6.9	Violet	Blue	

1 part 0.1% neutral red in alc. 1 part 0.1% methylene blue in alc.	*	7.0	Violet-blue	Green	Violet blue at pH 7.0†
1 part 0.1% neutral red in alc. 1 part 0.1% bromthymol blue in alc.		7.2	Rose	Green	Dirty green at pH 7.4, pale rose at 7.2, clear rose at 7.0
2 parts 0.1% cyanine in 50% alc. 1 part 0.1% phenol red in 50% alc.		7.3	Yellow	Violet	Orange at pH 7.2, beautiful violet at 7.4, color fades on standing
1 part 0.1% bromthymol blue sodium salt in aq. 1 part 0.1% phenol red sodium salt in aq.		7.5	Yellow	Violet	Dirty green at pH 7.2, pale violet at 7.4, strong violet at 7.6†
1 part 0.1% cresol red sodium salt in aq. 3 parts 0.1% thymol blue sodium salt in aq.		8.3	Yellow	Violet	Rose at pH 8.2, distinctly violet at 8.4†
2 parts 0.1% α-naphtholphthalein in alc. 1 part 0.1% cresol red in alc.		8.3	Pale rose	Violet	Pale violet at pH 8.2, strong violet at 8.4
1 part 0.1% α-naphtholphthalein in alc. 3 parts 0.1% phenolphthalein in alc.		8.9	Pale rose	Violet	Pale green at pH 8.6, violet at 9.0
1 part 0.1% phenolphthalein in alc. 2 parts 0.1% methyl green in alc.	*	8.9	Green	Violet	Pale blue at pH 8.8, violet at 9.0
1 part 0.1% thymol blue in 50% alc. 3 parts 0.1% phenolphthalein in 50% alc.		9.0	Yellow	Violet	From yellow thru green to violet†
1 part 0.1% phenolphthalein in alc. 1 part 0.1% thymolphthalein in alc.		9.9	Colorless	Violet	Rose at pH 9.6, violet at 10; sharp color change
1 part 0.1% phenolphthalein in alc. 2 parts 0.2% Nile blue in alc.		10.0	Blue	Red	Violet at pH 10†
2 parts 0.1% thymolphthalein in alc. 1 part 0.1% alizarin yellow in alc.		10.2	Yellow	Violet	Sharp color change
2 parts 0.2% Nile blue in aq. 1 part 0.1% alizarin yellow in alc.		10.8	Green	Red-brown	

* Keep in a dark bottle. † Excellent indicator.

TABLE 8.25 Fluorescent Indicators

Name	pH Range	Color Change Acid to Base	Indicator Solution
Benzoflavine	−0.3 to 1.7	Yellow to green	1
3,6-Dihydroxyphthalimide	0 to 2.4	Blue to green	1
	6.0 to 8.0	Green to yellow/green	
Eosin (tetrabromofluorescein)	0 to 3.0	Non-fl to green	4, 1%
4-Ethoxyacridone	1.2 to 3.2	Green to blue	1
3,6-Tetramethyldiaminoxanthone	1.2 to 3.4	Green to blue	1
Esculin	1.5 to 2.0	Weak blue to strong blue	
Anthranilic acid	1.5 to 3.0	Non-fl to light blue	2 (50% ethanol)
	4.5 to 6.0	Light blue to dark blue	
	12.5 to 14	Dark blue to non-fl	
3-Amino-1-naphthoic acid	1.5 to 3.0	Non-fl to green	2 (as sulfate
	4.0 to 6.0	Green to blue	in 50% ethanol)
	11.6 to 13.0	Blue to non-fl	
1-Naphthylamino-6-sulfonamide	1.9 to 3.9	Non-fl to green	3
(also the 1-, 7-)	9.6 to 13.0	Green to non-fl	
2-Naphthylamino-6-sulfonamide	1.9 to 3.9	Non-fl to dark blue	3
(also the 2-, 8-)	9.6 to 13.0	Dark blue to non-fl	
1-Naphthylamino-5-sulfonamide	2.0 to 4.0	Non-fl to yellow/orange	3
	9.5 to 13.0	Yellow/orange to non-fl	
1-Naphthoic acid	2.5 to 3.5	Non-fl to blue	4
Salicylic acid	2.5 to 4.0	Non-fl to dark blue	4 (0.5%)
Phloxin BA extra	2.5 to 4.0	Non-fl to dark blue	2
(tetrachlorotetrabromofluorescein)			
Erythrosin B (tetraiodofluorescein)	2.5 to 4.0	Non-fl to light green	4 (0.2%)
2-Naphthylamine	2.8 to 4.4	Non-fl to violet	1
Magdala red	3.0 to 4.0	Non-fl to purple	
p-Aminophenylbenzenesulfonamide	3.0 to 4.0	Non-fl to light blue	3
2-Hydroxy-3-naphthoic acid	3.0 to 6.8	Blue to green	4 (0.1%)
Chromotropic acid	3.1 to 4.4	Non-fl to light blue	4 (5%)
1-Naphthionic acid	3 to 4	Non-fl to blue	4
	10 to 12	Blue to yellow-green	
1-Naphthylamine	3.4 to 4.8	Non-fl to blue	1
5-Aminosalicylic acid	3.1 to 4.4	Non-fl to light green	1 (0.2% fresh)
Quinine	3.0 to 5.0	Blue to weak violet	1 (0.1%)
	9.5 to 10.0	Weak violet to non-fl	
o-Methoxybenzaldehyde	3.1 to 4.4	Non-fl to green	4 (0.2%)
o-Phenylenediamine	3.1 to 4.4	Green to non-fl	5
p-Phenylenediamine	3.1 to 4.4	Non-fl to orange/yellow	5
Morin (2′,4′,3,5,7-pentahydroxyflavone)	3.1 to 4.4	Non-fl to green	6 (0.2%)
	8 to 9.8	Green to yellow/green	
Thioflavine S	3.1 to 4.4	Dark blue to light blue	6 (0.2%)
Fluorescein	4.0 to 4.5	Pink/green to green	4 (1%)
Dichlorofluorescein	4.0 to 6.6	Blue green to green	1
β-Methylesculetin	4.0 to 6.2	Non-fl to blue	1
	9.0 to 10.0	Blue to light green	
Quininic acid	4.0 to 5.0	Yellow to blue	6 (satd)
β-Naphthoquinoline	4.4 to 6.3	Blue to non-fl	3
Resorufin (7-oxyphenoxazone)	4.4 to 6.4	Yellow to orange	

Indicator solutions: 1, 1% solution in ethanol; 2, 0.1% solution in ethanol; 3, 0.05% solution in 90% ethanol; 4, sodium or potassium salt in distilled water; 5, 0.2% solution in 70% ethanol; 6, distilled water.

Reference: G.F. Kirkbright, "Fluorescent Indicators," Chap. 9 in *Indicators,* E. Bishop (ed.), Pergamon Press, Oxford, 1972.

TABLE 8.25 Fluorescent Indicators (*Continued*)

Name	pH Range	Color Change Acid to Base	Indicator Solution
Acridine	5.2 to 6.6	Green to violet	2
3,6-Dihydroxyxanthone	5.4 to 7.6	Non-fl to blue/violet	1
5,7-Dihydroxy-4-methylcoumarin	5.5 to 5.8	Light blue to dark blue	
3,6-Dihydroxyphthalic acid dinitrile	5.8 to 8.2	Blue to green	1
1,4-Dihydroxybenzenedisulfonic acid	6 to 7	Non-fl to light blue	4 (0.1%)
Luminol	6 to 7	Non-fl to blue	
2-Naphthol-6-sulfonic acid	5–7 to 8–9	Non-fl to blue	4
Quinoline	6.2 to 7.2	Blue to non-fl	6 (satd)
1-Naphthol-5-sulfonic acid	6.5 to 7.5	Non-fl to green	6 (satd)
Umbelliferone	6.5 to 8.0	Non-fl to blue	
Magnesium-8-hydroxyquinolinate	6.5 to 7.5	Non-fl to yellow	6 (0.1% in 0.01 *M* HCl)
Orcinaurine	6.5 to 8.0	Non-fl to green	6 (0.03%)
Diazo brilliant yellow	6.5 to 7.5	Non-fl to blue	
Coumaric acid	7.2 to 9.0	Non-fl to green	1
β-Methylumbelliferone	>7.0	Non-fl to blue	2 (0.3%)
Harmine	7.2 to 8.9	Blue to yellow	
2-Naphthol-6,8-disulfonic acid	7.5 to 9.1	Blue to light blue	4
Salicylaldehyde semicarbazone	7.6 to 8.0	Yellow to blue	2
1-Naphthol-2-sulfonic acid	8.0 to 9.0	Dark blue to light blue	4
Salicylaldehyde acetylhydrazone	8.3	Non-fl to green/blue	2
Salicylaldehyde thiosemicarbazone	8.4	Non-fl to blue/green	2
1-Naphthol-4-sulfonic acid	8.2	Dark blue to light blue	4
Naphthol AS	8.2 to 10.3	Non-fl to yellow/green	4
2-Naphthol	8.5 to 9.5	Non-fl to blue	2
Acridine orange	8.4 to 10.4	Non-fl to yellow/green	1
Orcinsulfonephthalein	8.6 to 10.0	Non-fl to yellow	
2-Naphthol-3,6-disulfonic acid	9.0 to 9.5	Dark blue to light blue	4
Ethoxyphenylnaphthostilbazonium chloride	9 to 11	Green to non-fl	1
o-Hydroxyphenylbenzothiazole	9.3	Non-fl to blue green	2
o-Hydroxyphenylbenzoxazole	9.3	Non-fl to blue/violet	2
o-Hydroxyphenylbenzimidazole	9.9	Non-fl to blue/violet	2
Coumarin	9.5 to 10.5	Non-fl to light green	
6,7-Dimethoxyisoquinoline-1-carboxylic acid	9.5 to 11.0	Yellow to blue	0.1% in glycerine/ethanol/water in 2 : 2 : 18 ratio
1-Naphthylamino-4-sulfonamide	9.5 to 13.0	Dark blue to white/blue	3

TABLE 8.26 Selected List of Oxidation-Reduction Indicators

Name	Reduction Potential (30°C) in Volts at pH = 0	Reduction Potential (30°C) in Volts at pH = 7	Suitable pH Range	Color Change Upon Oxidation
Bis(5-bromo-1,10-phenanthroline) ruthenium(II) dinitrate	1.41*			Red to faint blue
Tris(5-nitro-1,10-phenanthroline) iron(II) sulfate	1.25*			Red to faint blue
Iron(II)-2,2′,2″-tripyridine sulfate	1.25*			Pink to faint blue
Tris(4,7-diphenyl-1,10-phenanthroline) iron(II) disulfate	1.13 (4.6 *M* H_2SO_4)* 0.87 (1.0 *M* H_2SO_4)*			Red to faint blue
o,m′-Diphenylaminedicarboxylic acid	1.12			Colorless to blue-violet
Setopaline	1.06 (*trans*)†			Yellow to orange
p-Nitrodiphenylamine	1.06			Colorless to violet
Tris(1,10-phenanthroline)-iron(II) sulfate	1.06 (1.00 *M* H_2SO_4)* 1.00 (3.0 *M* H_2SO_4)* 0.89 (6.0 *M* H_2SO_4)*			Red to faint blue
Setoglaucine O	1.01 (*trans*)†			Yellow-green to yellow-red
Xylene cyanole FF	1.00 (*trans*)†			Yellow-green to pink
Erioglaucine A	1.00 (*trans*)†			Green-yellow to bluish red
Eriogreen	0.99 (*trans*)†			Green-yellow to orange
Tris(2,2′-bipyridine)-iron(II) hydrochloride	0.97*			Red to faint blue
2-Carboxydiphenylamine [*N*-phenyl-anthranilic acid]	0.94			Colorless to pink
Benzidine dihydrochloride	0.92			Colorless to blue
o-Toluidine	0.87			Colorless to blue
Bis(1,10-phenanthroline)-osmium(II) perchlorate	0.859 (0.1 *M* H_2SO_4)			Green to pink
Diphenylamine-4-sulfonate (Na salt)	0.85			Colorless to violet

3,3′-Dimethoxybenzidine dihydrochloride [*o*-dianisidine]	0.85			Colorless to red
Ferrocyphen	0.81			Yellow to violet
4′-Ethoxy-2,4-diaminoazobenzene	0.76			Red to pale yellow
N,N-Diphenylbenzidine	0.76			Colorless to violet
Diphenylamine	0.76			Colorless to violet
N,N-Dimethyl-*p*-phenylenediamine	0.76			Colorless to red
Variamine blue B hydrochloride	0.712‡	0.310	1.5–6.3	Colorless to blue
N-Phenyl-1,2,4-benzenetriamine	0.70			Colorless to red
Bindschedler's green	0.680‡	0.224	2–9.5	
2,6-Dichloroindophenol (Na salt)	0.668‡	0.217	6.3–11.4	Colorless to blue
2,6-Dibromophenolindophenol	0.668‡	0.216	7.0–12.3	Colorless to blue
Brilliant cresyl blue [3-amino-9-dimethyl-amino-10-methylphenoxyazine chloride]	0.583	0.047	0–11	Colorless to blue
Iron(II)-tetrapyridine chloride	0.59			Red to faint blue
Thionine [Lauth's violet]	0.563‡	0.064	1–13	Colorless to violet
Starch (soluble potato, I_3^- present)	0.54			Colorless to blue
Gallocyanine (25°C)		0.021		Colorless to violet-blue
Methylene blue	0.532‡	0.011	1–13	Colorless to blue
Nile blue A [aminonaphthodiethylamino-phenoxazine sulfate]	0.406‡	−0.119	1.4–12.3	Colorless to blue
Indigo-5,5′,7,7′-tetrasulfonic acid (Na salt)	0.365‡	−0.046	<9	Colorless to blue
Indigo-5,5′,7-trisulfonic acid (Na salt)	0.332‡	−0.081	<9	Colorless to blue
Indigo-5,5′-disulfonic acid (Na salt)	0.291‡	−0.125	<9	Colorless to blue
Phenosafranine	0.280‡	−0.252	1–11	Colorless to violet-blue
Indigo-5-monosulfonic acid (Na salt)	0.262‡	−0.157	<9	Colorless to blue
Safranine T	0.24‡	−0.289	1–12	Colorless to violet-blue
Bis(dimethylglyoximato)-iron(II) chloride	0.155		6–10	Red to colorless
Induline scarlet	0.047‡	−0.299	3–8.6	Colorless to red
Neutral red		−0.323	2–11	Colorless to red-violet

* Transition point is at higher potential than the tabulated formal potential because the molar absorptivity of the reduced form is very much greater than that of the oxidized form.

† *Trans* = first noticeable color transition; often 60 mV less than $E°$

‡ Values of $E°$ are obtained by extrapolation from measurements in weakly acid or weakly alkaline systems.

8.6 ELECTRODE POTENTIALS

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C

Standard potentials are tabulated except when a solution composition is stated; the latter are formal potentials and the concentrations are in mol/liter.

Half-reaction	Standard or formal potential	Solution composition
Actinium		
$Ac^{3+} + 3e^- = Ac$	−2.13	
Aluminum		
$Al^{3+} + 3e^- = Al$	−1.676	
$AlF_6^{3-} + 3e^- = Al + 6F^-$	−2.07	
$Al(OH)_4^- + 3e^- = Al + 4OH^-$	−2.310	
Americium		
$AmO_2^{2+} + 4H^+ + 2e^- = Am^{4+} + 2H_2O$	1.20	
$AmO_2^{2+} + e^- = AmO_2^+$	1.59	
$AmO_2^+ + 4H^+ + e^- = Am^{4+} + 2H_2O$	0.82	
$AmO_2^+ + 4H^+ + 2e^- = Am^{3+} + 2H_2O$	1.72	
$Am^{4+} + e^- = Am^{3+}$	2.62	
$Am^{4+} + 4e^- = Am$	−0.90	
$Am^{3+} + 3e^- = Am$	−2.07	
Antimony		
$Sb(OH)_4^- + 2e^- = SbO_2^- + 2OH^- + 2H_2O$	−0.465	1 NaOH
$SbO_2^- + 2H_2O + 3e^- = Sb + 4OH^-$	0.639	1 NaOH
$Sb + 3H_2O + 3e^- = SbH_3 + 3OH^-$	−1.338	1 NaOH
$Sb_2O_5 + 6H^+ + 4e^- = 2SbO^+ + 3H_2O$	0.605	
$Sb_2O_5 + 4H^+ + 4e^- = Sb_2O_3 + 2H_2O$	0.699	
$Sb_2O_5 + 2H^+ + 2e^- = Sb_2O_4 + H_2O$	1.055	
$Sb_2O_4 + 2H^+ + 2e^- = Sb_2O_3 + H_2$	0.342	
$SbO^+ + 2H^+ + 3e^- = Sb + H_2O$	0.204	
$Sb + 3H^+ + 3e^- = SbH_3$	−0.510	
Arsenic		
$H_3AsO_4 + 2H^+ + 2e^- = HAsO_2 + 2H_2O$	0.560	
$HAsO_2 + 3H^+ + 3e^- = As + 2H_2O$	0.240	
$As + 3H^+ + 3e^- = AsH_3$	−0.225	
$AsO_4^{3-} + 2H^+ + 2e^- = AsO_2^- + 4OH^-$	−0.67	
$AsO_2^- + 2H_2O + 3e^- = As + 4OH^-$	−0.68	
$As + 3H_2O + 3e^- = AsH_3 + 3OH^-$	−1.37	
Astatine		
$HAtO_3 + 4H^+ + 4e^- = HAtO + 2H_2$	*ca.* 1.4	
$2HAtO + 2H^+ + 2e^- = At_2 + 2H_2O$	*ca.* 0.7	
$At_2 + 2e^- = 2At^-$	0.20	
Barium		
$BaO_2 + 4H^+ + 2e^- = Ba^{2+} + 2H_2O$	2.365	
$Ba^{2+} + 2e^- = Ba$	−2.92	

Source: A. J. Bard, R. Parsons, and J. Jordan (eds.), *Standard Potentials in Aqueous Solution* (prepared under the auspices of the International Union of Pure and Applied Chemistry), Marcel Dekker, New York, 1985; G. Charlot et al., *Selected Constants: Oxidation-Reduction Potentials of Inorganic Substances in Aqueous Solution,* Butterworths, London, 1971.

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Berkelium		
$Bk^{4+} + 4e^- = Bk$	−1.05	
$Bk^{4+} + e^- = Bk^{3+}$	1.67	
$Bk^{3+} + 3e^- = Bk$	−2.01	
Beryllium		
$Be^{2+} + 2e^- = Be$	−1.99	
Bismuth		
Bi_2O_4 (bismuthate) $+ 4H^+ + 2e^- = 2BiO^+ + 2H_2O$	1.59	
$Bi^{3+} + 3e^- = Bi$	0.317	
$Bi + 3H^+ + 3e^- = BiH_3$	−0.97	
$BiCl_4^- + 3e^- = Bi + 4Cl^-$	0.199	
$BiBr_4^- + 3e^- = Bi + 4Br^-$	0.168	
$BiOCl + 2H^+ + 3e^- = Bi + H_2O + Cl^-$	0.170	
Boron		
$B(OH)_3 + 3H^+ + 3e^- = B + 3H_2O$	−0.890	
$BO_2^- + 6H_2O + 8e^- = BH_3^- + 8OH^-$	−1.241	
$B(OH)_4^- + 3e^- = B + 4OH^-$	−1.811	
Bromine		
$BrO_4^- + 2H^+ + 2e^- = BrO_3^- + H_2O$	1.853	
$BrO_3^- + 6H^+ + 6e^- = Br^- + 3H_2O$	1.478	
$BrO_3^- + 5H^+ + 4e^- = HBrO + 2H_2O$	1.444	
$2BrO_3^- + 12H^+ + 10e^- = Br_2 + 6H_2O$	1.5	
$2HBrO + 2H^+ + 2e^- = Br_2 + 2H_2O$	1.604	
$HBrO + H^+ + 2e^- = Br^- + H_2O$	1.341	
$BrO^- + H_2O + 2e^- = Br^- + 2OH^-$	0.76	1 NaOH
$Br_3^- + 2e^- = 3Br^-$	1.050	
$Br_2(aq) + 2e^- = 2Br^-$	1.087	
Cadmium		
$Cd^{2+} + 2e^- = Cd$	−0.403	
$Cd^{2+} + Hg + 2e^- = Cd(Hg)$	−0.352	
$CdCl_4^{2-} + 2e^- = Cd + 4Cl^-$	−0.453	
$Cd(CN)_4^{2-} + 2e^- = Cd + 4CN^-$	−0.943	
$Cd(NH_3)_4^{2+} + 2e^- = Cd + 4NH_3$	−0.622	
$Cd(OH)_4^{2-} + 2e^- = Cd + 4OH^-$	−0.670	
Calcium		
$CaO_2 + 4H^+ + 2e^- = Ca^{2+} + H_2O$	2.224	
$Ca^{2+} + 2e^- = Ca$	−2.84	
$Ca + 2H^+ + 2e^- = CaH_2$	0.776	
Californium		
$Cf^{3+} + 3e^- = Cf$	−1.93	
$Cf^{3+} + e^- = Cf^{2+}$	−1.6	
$Cf^{2+} + 2e^- = Cf$	−2.1	
Carbon		
$CO_2 + 2H^+ + 2e^- = CO + H_2O$	−0.106	
$CO_2 + 2H^+ + 2e^- = HCOOH$	−0.20	
$2CO_2 + 2H^+ + 2e^- = H_2C_2O_4$	−0.481	
$C_2O_4^{2-} + 2H^+ + 2e^- = 2HCOO^-$	0.145	
$HCOOH + 2H^+ + 2e^- = HCHO + H_2O$	0.034	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
$C_2N_2 + 2H^+ + 2e^- = 2HCN$	0.373	
$HCNO + 2H^+ + 2e^- = CO + H_2O$	0.330	
$HCHO + 2H^+ + 2e^- = CH_3OH$	0.2323	
$CNO^- + H_2O + 2e^- = CN^- + 2OH^-$	−0.97	
Cerium		
$Ce(IV) + e^- = Ce(III)$	1.70	1 $HClO_4$
	1.61	1 HNO_3
	1.44	0.5 H_2SO_4
	1.28	1 HCl
$Ce^{3+} + 3e^- = Ce$	−2.34	
Cesium		
$Cs^+ + e^- = Cs$	−2.923	
$Cs^+ + Hg + e^- = Cs(Hg)$	−1.78	
Chlorine		
$ClO_4^- + 2H^+ + 2e^- = ClO_3^- + H_2O$	1.201	
$2ClO_4^- + 16H^+ + 14e^- = Cl_2 + 8H_2O$	1.392	
$ClO_4^- + 8H^+ + 8e^- = Cl^- + 4H_2O$	1.388	
$ClO_3^- + 2H^+ + e^- = ClO_2(g) + H_2O$	1.175	
$ClO_3^- + 3H^+ + 2e^- = HClO_2 + H_2O$	1.181	
$2ClO_3^- + 12H^+ + 10e^- = Cl_2 + 6H_2O$	1.468	
$ClO_3^- + 6H^+ + 6e^- = Cl^- + 3H_2O$	1.45	
$ClO_2(g) + H^+ + e^- = HClO_2$	1.188	
$HClO_2 + 2H^+ + 2e^- = HClO + H_2O$	1.64	
$HClO_2 + 3H^+ + 4e^- = Cl^- + 2H_2O$	1.584	
$2HClO_2 + 6H^+ + 6e^- = Cl_2(g) + 4H_2O$	1.659	
$2ClO^- + 2H_2O + 2e^- = Cl_2(g) + 4OH^-$	0.421	1 NaOH
$ClO^- + H_2O + 2e^- = Cl^- + 2OH^-$	0.890	1 NaOH
$Cl_3^- + 2e^- = 3Cl^-$	1.415	
$Cl_2(aq) + 2e^- = 2Cl^-$	1.396	
Chromium		
$Cr_2O_7^{2-} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$	1.36	
	1.15	0.1 H_2SO_4
	1.03	1 $HClO_4$
$CrO_4^{2-} + 4H_2O + 3e^- = Cr(OH)_4^- + 4OH^-$	−0.13	1 NaOH
$Cr^{3+} + e^- = Cr^{2+}$	−0.424	
$Cr^{3+} + 3e^- = Cr$	−0.74	
$Cr^{2+} + 2e^- = Cr$	0.90	
Cobalt		
$CoO_2 + 4H^+ + e^- = Co^{3+} + 2H_2O$	1.416	
$Co(H_2O)_6^{3+} + e^- = Co(H_2O)_6^{2+}$	1.92	
$Co(NH_3)_6^{3+} + e^- = Co(NH_3)_6^{2+}$	0.058	7 NH_3
$Co(OH)_3 + e^- = Co(OH)_2 + OH^-$	0.17	
$Co(en)_3^{3+} + e^- = Co(en)_3^{2+}$ [en = ethylenediamine]	−0.2	0.1 en
$Co(CN)_6^{3-} + e^- = Co(CN)_5^{2-} + CN^-$	−0.8	0.8 KOH
$Co^{2+} + 2e^- = Co$	−0.277	
$Co(NH_3)_6^{2+} + 2e^- = Co + 6NH_3$	−0.422	
$[Co(CO)_4]_2 + 2e^- = 2Co(CO)_4^-$	−0.40	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Copper		
$Cu^{2+} + 2e^- = Cu$	0.340	
$Cu^{2+} + e^- = Cu^+$	0.159	
$Cu^+ + e^- = Cu$	0.520	
$Cu^{2+} + Cl^- + e^- = CuCl$	0.559	
$Cu^{2+} + 2Br^- + e^- = CuBr_2^-$	0.52	1 KBr
$Cu^{2+} + I^- + e^- + CuI$	0.86	
$Cu^{2+} + 2CN^- + e^- = Cu(CN)_2^-$	1.12	
$Cu(NH_3)_4^{2+} + e^- = Cu(NH_3)_2^+ + 2NH_3$	0.10	1 NH_3
$Cu(en)_2^{2+} + e^- = Cu(en)^+ + en$	−0.35	
$Cu(CN)_2^- + e^- = Cu + 2CN^-$	−0.44	
$CuCl_3^{2-} + e^- = Cu + 3Cl^-$	0.178	1 HCl
$Cu(NH_3)_2^+ + e^- = Cu + 2NH_3$	−0.100	
Curium		
$Cm^{4+} + e^- = Cm^{3+}$	3.2	1 $HClO_4$
$Cm^{3+} + 3e^- = Cm$	−2.06	
Dysprosium		
$Dy^{3+} + 3e^- = Dy$	−2.29	
$Dy^{3+} + e^- = Dy^{2+}$	−2.5	
$Dy^{2+} + 2e^- = Dy$	−2.2	
Einsteinium		
$Es^{3+} + 3e^- = Es$	−2.0	
$Es^{3+} + e^- = Es^{2+}$	−1.5	
$Es^{2+} + 2e^- = Es$	−2.2	
Erbium		
$Er^{3+} + 3e^- = Er$	−2.32	
Europium		
$Eu^{3+} + 3e^- = Eu$	−1.99	
$Eu^{3+} + e^- = Eu^{2+}$	−0.35	
$Eu^{2+} + 2e^- = Eu$	−2.80	
Fermium		
$Fm^{3+} + 3e^- = Fm$	−1.96	
$Fm^{3+} + e^- = Fm^{2+}$	−1.15	
$Fm^{2+} + 2e^- = Fm$	−2.37	
Fluorine		
$F_2 + 2H^+ + 2e^- = 2HF$	3.053	
$F_2 + H^+ + 2e^- = HF_2^-$	2.979	
$F_2 + 2e^- = 2F^-$	2.87	
$OF_2 + 3H^+ + 4e^- = HF_2^- + H_2O$	2.209	
Francium		
$Fr^+ + e^- = Fr$	*ca.* −2.9	
Gadolinium		
$Gd^{3+} + 3e^- = Gd$	−2.28	
Gallium		
$Ga^{3+} + 3e^- = Ga$	−0.529	
$Ga^{3+} + e^- = Ga^{2+}$	−0.65	
$Ga^{2+} + 2e^- = Ga$	−0.45	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Germanium		
$GeO_2(tetr) + 2H^+ + 2e^- = GeO(yellow) + H_2O$	−0.255	
$GeO_2(tetr) + 4H^+ + 2e^- = Ge^{2+} + 2H_2O$	−0.210	
$GeO_2(hex) + 4H^+ + 2e^- = Ge^{2+} + 2H_2O$	−0.132	
$H_2GeO_3 + 4H^+ + 4e^- = Ge + 3H_2O$	0.012	
$Ge^{4+} + 2e^- = Ge^{2+}$	0.0	
$Ge^{2+} + 2e^- = Ge$	0.247	
$GeO + 2H^+ + 2e^- = Ge + H_2O$	−0.255	
$Ge + 4H^+ + 4e^- = GeH_4$	−0.29	
Gold		
$Au^{3+} + 3e^- = Au$	1.52	
$Au^{3+} + 2e^- = Au^+$	1.36	
$Au^+ + e^- = Au$	1.83	
$AuCl_4^- + 2e^- = AuCl_2^- + 2Cl^-$	0.926	
$AuBr_4^- + 2e^- = AuBr_2^- + 2Br^-$	0.802	
$Au(SCN)_4^- + 2e^- = Au(SCN)_2^- + 2SCN^-$	0.623	
$AuBr_4^- + 3e^- = Au + 4Br^-$	0.854	
$AuCl_4^- + 3e^- = Au + 4Cl^-$	1.002	
$Au(SCN)_4^- + 3e^- = Au + 4SCN^-$	0.662	
$Au(OH)_3 + 3H^+ + 3e^- = Au + 3H_2O$	1.45	
$AuBr_2^- + e^- = Au + 2Br^-$	0.960	
$AuCl_2^- + e^- = Au + 2Cl^-$	1.15	
$AuI_2^- + e^- = Au + 2I^-$	0.576	
$Au(CN)_2^- + e^- = Au + 2CN^-$	−0.596	
$Au(SCN)_2 + e^- = Au + 2SCN^-$	0.69	
Hafnium		
$Hf^{4+} + 4e^- = Hf$	−1.70	
$HfO_2 + 4H^+ + 4e^- = Hf + 2H_2O$	−1.57	
Holmium		
$Ho^{3+} + 3e^- = Ho$	−2.23	
Hydrogen		
$2H^+ + 2e^- = H_2$	0.0000	
$2D^+ + 2e^- = D_2$	0.029	
$2H_2O + 2e^- = H_2 + 2OH^-$	−0.828	
Indium		
$In^{3+} + 3e^- = In$	−0.338	
$In^{3+} + 2e^- = In^+$	−0.444	
$In^+ + e^- = In$	−0.126	
Iodine		
$H_5IO_6 + H^+ + 2e^- = IO_3^- + 3H_2O$	1.603	
$IO_3^- + 5H^+ + 4e^- = HIO + 2H_2O$	1.14	
$HIO_3 + 5H^+ + 2Cl^- + 4e^- = ICl_2^- + 3H_2O$	1.214	
$2IO_3^- + 12H^+ + 10e^- = I_2(c) + 3H_2O$	1.195	
$IO_3^- + 3H_2O + 6e^- = I^- + 6OH^-$	0.257	
$2IBr_2^- + 2e^- = I_2Br^- + 3Br^-$	0.821	
$2IBr_2^- + 2e^- = I_2(c) + 4Br^-$	0.874	
$2IBr + 2e^- = I_2Br^- + Br^-$	0.973	
$2IBr + 2e^- = I_2 + 2Br^-$	1.02	
$2ICl + 2e^- = I_2(c) + 2Cl^-$	1.20	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
$2ICl_2^- + 2e^- = I_2(c) + 4Cl^-$	1.07	
$2ICN + 2H^+ + 2e^- = I_2(c) + 2HCN$	0.695	
$2ICN + 2H^+ + 2e^- = I_2(aq) + 2HCN$	0.609	
$2HIO + 2H^+ + 2e^- = I_2 + 2H_2O$	1.45	
$HIO + H^+ + 2e^- = I^- + H_2O$	0.985	
$I_3^- + 2e^- = 3I^-$	0.536	
$I_2(aq) + 2e^- = 2I^-$	0.621	
$I_2(c) + 2e^- = 2I^-$	0.5355	
Iridium		
$IrBr_6^{2-} + e^- = IrBr_6^{3-}$	0.805	
$IrCl_6^{2-} + e^- = IrCl_6^{3-}$	0.867	
$IrI_6^{2-} + e^- = IrI_6^{3-}$	0.49	
$IrO_2 + 4H^+ + e^- = Ir^{3+} + 2H_2O$	0.223	
$IrO_2 + 4H^+ + 4e^- = Ir + 2H_2O$	0.935	1 H_2SO_4
$Ir^{3+} + 3e^- = Ir$	1.156	
$IrCl_6^{2-} + 4e^- = Ir + 6Cl^-$	0.835	
$IrCl_6^{3-} + 3e^- = Ir + 6Cl^-$	0.77	
Iron		
$FeO_4^{2-} + 8H^+ + 3e^- = Fe^{3+} + 4H_2O$	2.2	
$FeO_4^{2-} + 2H_2O + 3e^- = FeO_2^- + 4OH^-$	0.55	10 NaOH
$Fe^{3+} + e^- = Fe^{2+}$	0.771	
	0.70	1 HCl
	0.67	0.5 H_2SO_4
	0.44	0.3 H_3PO_4
$Fe(CN)_6^{3-} + e^- = Fe(CN)_6^{4-}$	0.361	
	0.71	1 HCl
$Fe(EDTA)^- + e^- = Fe(EDTA)^{2-}$	0.12	0.1 EDTA, pH 4–6
$Fe(OH)_4^- + e^- = Fe(OH)_4^{2-}$	−0.73	1 NaOH
$Fe^{2+} + 2e^- = Fe$	−0.44	
$[Fe(CO)_4]_3 + 6e^- = 3Fe(CO)_4^{2-}$	−0.70	
Lanthanum		
$La^{3+} + 3e^- = La$	−2.38	
Lawrencium		
$Lr^{3+} + 3e^- = Lr$	−2.0	
Lead		
$Pb^{4+} + 2e^- = Pb^{2+}$	1.65	
$PbO_2(alpha) + SO_4^{2-} + 4H^+ + 2e^- = PbSO_4 + 2H_2O$	1.690	
$PbO_2 + 4H^+ + 2e^- = Pb^{2+} + 2H_2O$	1.46	
$PbO_2 + 2H^+ + 2e^- = PbO + H_2O$	0.28	
$PbO^{2-} + H_2O + 2e^- = HPbO_2^- + 3OH^-$	0.3	2 NaOH
$Pb^{2+} + 2e^- = Pb$	−0.126	
$HPbO_2^- + H_2O + 2e^- = Pb + 3OH^-$	−0.54	
$PbHPO_4 + 2e^- = Pb + HPO_4^{2-}$	−0.465	
$PbSO_4 + 2e^- = Pb + SO_4^{2-}$	−0.356	
$PbF_2 + 2e^- = Pb + 2F^-$	−0.344	
$PbCl_2 + 2e^- = Pb + 2Cl^-$	−0.268	
$PbBr_2 + 2e^- = Pb + 2Br^-$	−0.280	
$PbI_2 + 2e^- = Pb + 2I^-$	−0.365	
$Pb + 2H^+ + 2e^- = PbH_2$	−1.507	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Lithium		
$Li^+ + e^- = Li$	−3.040	
$Li^+ + Hg + e^- = Li(Hg)$	−2.00	
Lutetium		
$Lu^{3+} + 3e^- = Lu$	−2.30	
Magnesium		
$Mg^{2+} + 2e^- = Mg$	−2.356	
$Mg(OH)_2 + 2e^- = Mg + 2OH^-$	−2.687	
Manganese		
$MnO_4^- + e^- = MnO_4^{2-}$	0.56	
$MnO_4^- + 4H^+ + 3e^- = MnO_2(beta) + 2H_2O$	1.70	
$MnO_4^- + 2H_2O + 3e^- = MnO_2 + 4OH^-$	0.60	
$MnO_4^- + 8H^+ + 5e^- = Mn^{2+} + 4H_2O$	1.51	
$MnO_4^{2-} + e^- = MnO_4^{3-}$	0.27	
$MnO_4^{2-} + 2H_2O + 2e^- = MnO_2 + 4OH^-$	0.62	
$MnO_4^{3-} + 2H_2O + e^- = MnO_2 + 4OH^-$	0.96	
$MnO_2 + 4H^+ + e^- = Mn^{3+} + 2H_2O$	0.95	
$MnO_2(beta) + 4H^+ + 2e^- = Mn^{2+} + 2H_2O$	1.23	
$Mn^{3+} + e^- = Mn^{2+}$	1.5	
$Mn(H_2P_2O_7)_3^{3-} + 2H^+ + e^- = Mn(H_2P_2O_7)_2^{2-} + H_4P_2O_7$	1.15	0.4 $H_2P_2O_7^{2-}$
$Mn(CN)_6^{3-} + e^- = Mn(CN)_6^{4-}$	−0.24	1.5 NaCN
$Mn^{2+} + 2e^- = Mn$	−1.17	
Mendelevium		
$Md^{3+} + 3e^- = Md$	−1.7	
$Md^{3+} + e^- = Md^{2+}$	−0.15	
$Md^{2+} + 2e^- = Md$	−2.4	
Mercury		
$2Hg^{2+} + 2e^- = Hg_2^{2+}$	0.911	
$2HgCl_2 + 2e^- = Hg_2Cl_2 + 2Cl^-$	0.63	
$Hg^{2+} + 2e^- = Hg(lq)$	0.8535	
$HgO(c,red) + 2H^+ + 2e^- = Hg + H_2O$	0.926	
$Hg_2^{2+} + 2e^- = 2Hg$	0.7960	
$Hg_2F_2 + 2e^- = 2Hg + 2F^-$	0.656	
$Hg_2Cl_2 + 2e^- = 2Hg + 2Cl^-$	0.2682	
$Hg_2Br_2 + 2e^- = 2Hg + 2Br^-$	0.1392	
$Hg_2I_2 + 2e^- = 2Hg + 2I^-$	−0.0405	
$Hg_2SO_4 + 2e^- = 2Hg + SO_4^{2-}$	0.614	
Molybdenum		
$MoO_4^{2-} + 4H_2O + 6e^- = Mo + 8OH^-$	−0.913	
$H_2MoO_4 + 6H^+ + 6e^- = Mo + 4H_2O$	0.114	
$H_2MoO_4 + 2H^+ + 2e^- = MoO_2 + 2H_2O$	0.646	
$MoO_2 + 4H^+ + 4e^- = Mo + 2H_2O$	−0.152	
$H_2MoO_4 + 6H^+ + 3e^- = Mo^{3+} + 4H_2O$	0.428	
$Mo(CN)_8^{3-} + e^- = Mo(CN)_8^{4-}$	0.725	
$Mo^{3+} + 3e^- = Mo$	−0.2	
Neodynium		
$Nd^{3+} + 3e^- = Nd$	−2.32	
$Nd^{3+} + e^- = Nd^{2+}$	−2.6	
$Nd^{2+} + 2e^- = Nd$	−2.2	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Neptunium		
$NpO_3^+ + 2H^+ + e^- = NpO_2^{2+} + H_2O$	2.04	
$NpO_2^{2+} + e^- = NpO_2^+$	1.34	
$NpO_2^{2+} + 4H^+ + 2e^- = Np^{4+} + 2H_2O$	0.95	
$Np^{4+} + e^- = Np^{3+}$	0.18	
$Np^{4+} + 4e^- = Np$	−1.30	
$Np^{3+} + 3e^- = Np$	−1.79	
Nickel		
$NiO_4^{2-} + 4H^+ + 2e^- = NiO_2 + 2H_2O$	1.8	
$NiO_2 + 4H^+ + 2e^- = Ni^{2+} + 2H_2O$	1.593	
$NiO_2 + 2H_2O + 2e^- = Ni(OH)_2 + 2OH^-$	0.490	
$Ni(CN)_4^{2-} + e^- = Ni(CN)_3^{2-} + CN^-$	−0.401	
$Ni^{2+} + 2e^- = Ni$	−0.257	
$Ni(OH)_2 + 2e^- = Ni + 2OH^-$	−0.72	
$Ni(NH_3)_6^{2+} + 2e^- = Ni + 6NH_3$	−0.49	
Niobium		
$Nb_2O_5 + 10H^+ + 4e^- = 2Nb^{3+} + 5H_2O$	−0.1	
$Nb_2O_5 + 10H^+ + 10e^- = 2Nb + 5H_2O$	−0.65	
$Nb^{3+} + 3e^- = Nb$	−1.1	
Nitrogen		
$2NO_3^- + 4H^+ + 2e^- = N_2O_4 + 2H_2O$	0.803	
$NO_3^- + 3H^+ + 2e^- = HNO_2 + H_2O$	0.94	
$N_2O_4 + 2H^+ + 2e^- = 2HNO_2$	1.07	
$HNO_2 + H^+ + e^- = NO + H_2O$	0.996	
$2HNO_2 + 4H^+ + 4e^- = N_2O(g) + 3H_2O$	1.297	
$2HNO_2 + 4H^+ + 4e^- = H_2N_2O_2 + 2H_2O$	0.86	
$2NO + 2H^+ + 2e^- = H_2N_2O_2$	0.71	
$2NO + 2H^+ + 2e^- = N_2O + H_2O$	1.59	
$H_2N_2O_2 + 6H^+ + 4e^- = 2HONH_3^+$	0.496	
$N_2O + 2H^+ + 2e^- = N_2 + H_2O$	1.77	
$N_2O + 6H^+ + H_2O + 4e^- = 2HONH_3^+$	−0.05	
$N_2 + 2H_2O + 4H^+ + 2e^- = 2HONH_3^+$	−1.87	
$N_2 + 5H^+ + 4e^- = N_2H_5^+$	−0.23	
$HONH_3^+ + 2H^+ + 2e^- = NH_4^+ + H_2O$	1.35	
$2HONH_3^+ + H^+ + 2e^- = N_2H_5^+ + 2H_2O$	1.41	
$N_2H_5^+ + 3H^+ + 2e^- = 2NH_4^+$	1.275	
$3N_2 + 2H^+ + 2e^- = 2HN_3$	−3.40	
Nobelium		
$No^{3+} + 3e^- = No$	−1.2	
$No^{3+} + e^- = No^{2+}$	1.4	
$No^{2+} + 2e^- = No$	−2.5	
Osmium		
$OsO_4(aq) + 4H^+ + 4e^- = OsO_2 \cdot 2H_2O + 2H_2O$	0.964	
$OsO_4(c, yellow) + 8H^+ + 8e^- = Os + 4H_2O$	0.85	
$OsO_2 + 4H^+ + 4e^- = Os + 2H_2O$	0.687	
$OsCl_6^{2-} + e^- = OsCl_6^{3-}$	0.45	
$OsBr_6^{2-} + e^- = OsBr_6^{3-}$	0.35	
Oxygen		
$O_3 + 2H^+ + 2e^- = O_2 + H_2O$	2.075	
$O_3 + H_2O + 2e^- = O_2 + 2OH^-$	1.240	1 NaOH

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
$O_2 + 4H^+ + 4e^- = 2H_2O$	1.229	
$O_2 + 2H^+ + 2e^- = H_2O$	0.695	
$O_2 + H_2O + 2e^- = HO_2^- + OH^-$	−0.076	
$H_2O_2 + 2H^+ + 2e^- = 2H_2O$	1.763	
$HO_2^- + H_2O + 2e^- = 3OH^-$	0.867	1 NaOH
$O_2 + 2H_2O + 4e^- = 4OH^-$	0.401	
Palladium		
$PdO_3 + 2H^+ + 2e^- = PdO_2 + H_2O$	2.030	
$PdCl_6^{2-} + 2e^- = PdCl_4^{2-} + 2Cl^-$	1.470	
$PdBr_6^{2-} + 2e^- = PdBr_4^{2-} + 2Br^-$	0.99	
$PdI_6^{2-} + 2e^- = PdI_4^{2-} + 2I^-$	0.48	
$Pd^{2+} + 2e^- = Pd$	0.915	
$PdCl_4^{2-} + 2e^- = Pd + 4Cl^-$	0.62	1 HCl
$PdBr_4^{2-} + 2e^- = Pd + 4Br^-$	0.49	
$Pd(NH_3)_4^{2+} + 2e^- = Pd + 4NH_3$	0.0	1 NH_3
$Pd(CN)_4^{2-} + 2e^- = Pd + 4CN^-$	−1.35	1 KCN
Phosphorus		
$H_3PO_4 + 2H^+ + 2e^- = H_3PO_3 + H_2O$	−0.276	
$2H_3PO_4 + 2H^+ + 2e^- = H_4P_2O_6 + 2H_2O$	−0.933	
$H_4P_2O_6 + 2H^+ + 2e^- = 2H_3PO_3$	0.380	
$H_3PO_3 + 2H^+ + 2e^- = HPH_2O_2 + H_2O$	−0.499	
$HPH_2O_2 + H^+ + e^- = P + 2H_2O$	−0.365	
$H_3PO_3 + 3H^+ + 3e^- = P + 3H_2O$	−0.502	
$2P(white) + 4H^+ + 4e^- = P_2H_4$	−0.100	
$P_2H_4 + 2H^+ + 2e^- = 2PH_3$	−0.006	
$P(white) + 3H^+ + 3e^- = PH_3$	−0.063	
Platinum		
$PtO_3 + 2H^+ + 2e^- = PtO_2 + H_2O$	2.0	
$PtO_2 + 2H^+ + 2e^- = PtO + H_2O$	1.045	
$PtCl_6^{2-} + 2e^- = PtCl_4^{2-} + 2Cl^-$	0.726	
$PtBr_6^{2-} + 2e^- = PtBr_4^{2-} + 2Br^-$	0.613	1 KBr
$PtI_6^{2-} + 2e^- = PtI_4^{2-} + 2I^-$	0.321	1 KI
$Pt^{2+} + 2e^- = Pt$	1.188	
$PtCl_4^{2-} + 2e^- = Pt + 4Cl^-$	0.758	
$PtBr_4^{2-} + 2e^- = Pt + 4Br^-$	0.698	
Plutonium		
$PuO_2^{2+} + e^- = PuO_2^+$	1.02	
$PuO_2^{2+} + 4H^+ + 2e^- = Pu^{4+} + 2H_2O$	1.04	
$Pu^{4+} + e^- = Pu^{3+}$	1.01	
	0.80	1 H_3PO_4
	0.50	1 HF
$Pu^{4+} + 4e^- = Pu$	−1.25	
$Pu^{3+} + 3e^- = Pu$	−2.00	
Polonium		
$PoO_2 + 4H^+ + 2e^- = Po^{2+} + 2H_2O$	1.1	
$Po^{4+} + 4e^- = Po$	0.73	
$Po^{2+} + 2e^- = Po$	0.37	
$Po + 2H^+ + 2e^- = H_2Po$	*ca.* −1.0	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Potassium		
$K^+ + e^- = K$	−2.924	
$K^+ + Hg + e^- = K(Hg)$	*ca.* −1.9	
Praseodymium		
$Pr^{4+} + e^- = Pr^{3+}$	3.2	
$Pr^{3+} + e^- = Pr$	−2.35	
Promethium		
$Pm^{3+} + 3e^- = Pm$	−2.42	
Protoactinium		
$PaOOH^{2+} + 3H^+ + e^- = Pa^{4+} + 2H_2O$	−0.10	
$PaOOH^{2+} + 3H^+ + 5e^- = Pa + 2H_2O$	−1.19	
$Pa^{4+} + 4e^- = Pa$	−1.46	
Radium		
$Ra^{2+} + 2e^- = Ra$	−2.916	
Rhenium		
$ReO_4^- + 2H^+ + e^- = ReO_3 + H_2O$	0.768	
$ReO_4^- + 4H^+ + 3e^- = ReO_2 + 2H_2O$	0.51	
$ReO_4^- + 2H_2O + 3e^- = ReO_2 + 4OH^-$	−0.594	
$ReO_4^- + 6Cl^- + 8H^+ + 3e^- = ReCl_6^{2-} + 4H_2O$	0.12	
$2ReO_4^- + 10H^+ + 8e^- = Re_2O_3 + 5H_2O$	−0.808	
$ReO_3 + 2H^+ + 2e^- = ReO_2 + H_2O$	0.63	
$ReO_2 + 4H^+ + 4e^- = Re + 2H_2O$	0.22	
$ReCl_6^{2-} + 4e^- = Re + 6Cl^-$	0.51	
$Re + e^- = Re^-$	−0.10	
Rhodium		
$RhO_2 + 4H^+ + e^- = Rh^{3+} + 2H_2O$	1.881	
$Rh^{3+} + 3e^- = Rh$	0.76	
$RhCl_6^{3-} + 3e^- = Rh + 6Cl^-$	0.5	
Rubidium		
$Rb^+ + e^- = Rb$	−2.924	
$Rb^+ + Hg + e^- = Rb(Hg)$	−1.81	
Ruthenium		
$RuO_4 + e^- = RuO_4^-$	0.89	
$RuO_4 + 4H^+ + 4e^- = RuO_2 + 2H_2O$	1.4	
$RuO_4 + 8H^+ + 8e^- = Ru + 4H_2O$	1.04	
$RuO_4^- + e^- = RuO_4^{2-}$	0.593	
$RuO_4^{2-} + 4H^+ + 2e^- = RuO_2 + 2H_2O$	2.0	
$RuO_2 + 4H^+ + 4e^- = Ru + 2H_2O$	0.68	
$Ru(H_2O)_6^{3+} + e^- = Ru(H_2O)_6^{2+}$	0.249	
$Ru(NH_3)_6^{3+} + e^- = Ru(NH_3)_6^{2+}$	0.10	
$Ru(CN)_6^{3-} + e^- = Ru(CN)_6^{4-}$	0.86	
$Ru^{3+} + e^- = Ru^{2+}$	0.249	
Samarium		
$Sm^{3+} + 3e^- = Sm$	−2.30	
$Sm^{3+} + e^- = Sm^{2+}$	−1.55	
$Sm^{2+} + 2e^- = Sm$	−2.67	
Scandium		
$Sc^{3+} + 3e^- = Sc$	−2.03	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Selenium		
$SeO_4^{2-} + 4H^+ + 2e^- = H_2SeO_3 + H_2O$	1.151	
$H_2SeO_3 + 4H^+ + 4e^- = Se + 3H_2O$	0.74	
$Se(c) + 2H^+ + 2e^- = H_2Se(aq)$	−0.115	
$Se + H^+ + 2e^- = HSe^-$	−0.227	
$Se + 2e^- = Se^{2-}$	−0.670	1 NaOH
Silicon		
$SiO_2(quartz) + 4H^+ + 4e^- = Si + 2H_2O$	−0.909	
$SiO_2 + 2H^+ + 2e^- = SiO + H_2O$	−0.967	
$SiO_2 + 8H^+ + 8e^- = SiH_4 + 2H_2O$	−0.516	
$SiF_6^{2-} + 4e^- = Si + 6F^-$	−1.37	
$SiO + 2H^+ + 2e^- = Si + H_2O$	−0.808	
$Si + 4H^+ + 4e^- = SiH_4(g)$	−0.143	
Silver		
$AgO^+ + 2H^+ + e^- = Ag^{2+} + H_2O$	1.360	
$Ag_2O_3 + 2H^+ + 2e^- = 2AgO + H_2O$	1.569	
$Ag_2O_3 + H_2O + 2e^- = 2AgO + 2OH^-$	0.739	1 NaOH
$Ag_2O_3 + 6H^+ + 4e^- = 2Ag^+ + 3H_2O$	1.670	
$Ag^{2+} + e^- = Ag^+$	1.980	
$AgO + 2H^+ + e^- = Ag^+ + H_2O$	1.772	
$Ag^+ + e^- = Ag$	0.7991	
$Ag_2SO_4 + 2e^- = 2Ag + SO_4^{2-}$	0.653	
$Ag_2C_2O_4 + 2e^- = 2Ag + C_2O_4^{2-}$	0.47	
$Ag_2CrO_4 + 2e^- = 2Ag + CrO_4^{2-}$	0.447	
$Ag(NH_3)_2^+ + e^- = Ag + 2NH_3$	0.373	
$AgCl + e^- = Ag + Cl^-$	0.2223	
$AgBr + e^- = Ag + Br^-$	0.071	
$AgCN + e^- = Ag + CN^-$	−0.017	
$AgI + e^- = Ag + I^-$	−0.152	
$Ag(CN) + e^- = Ag + 2CN^-$	−0.31	
$AgSCN + e^- = Ag + SCN^-$	0.09	
$Ag_2S + 2e^- = 2Ag + S^{2-}$	−0.71	
Sodium		
$Na^+ + e^- = Na$	−2.713	
$Na^+ + Hg + e^- = Na(Hg)$	−1.84	
Strontium		
$SrO_2 + 4H^+ + 2e^- = Sr^{2+}$	2.33	
$Sr^{2+} + 2e^- = Sr$	−2.89	
Sulfur		
$S_2O_8^{2-} + 2e^- = 2SO_4^{2-}$	1.96	
$S_2O_8^{2-} + 2H^+ + 2e^- = 2HSO_4^-$	2.08	
$2SO_4^{2-} + 4H^+ + 2e^- = S_2O_6^{2-} + 2H_2O$	−0.25	
$SO_4^{2-} + 4H^+ + 2e^- = SO_2(aq) + H_2O$	0.158	
$SO_4^{2-} + H_2O + 2e^- = SO_3^{2-} + 2OH^-$	−0.936	
$S_2O_6^{2-} + 4H^+ + 2e^- = 2H_2SO_3$	0.569	
$S_2O_6^{2-} + 2e^- = 2SO_3^{2-}$	0.037	
$2HSO_3^- + 2H^+ + 2e^- = S_2O_4^{2-} + 2H_2O$	0.099	
$2SO_3^{2-} + 2H_2O + 2e^- = S_2O_4^{2-} + 4OH^-$	−1.13	
$4H_2SO_3 + 4H^+ + 6e^- = S_4O_6^{2-} + 6H_2O$	0.507	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
$4HSO_3^- + 8H^+ + 6e^- = S_4O_6^{2-} + 6H_2O$	0.577	
$2SO_2(aq) + 2H^+ + 4e^- = S_2O_3^{2-} + H_2O$	0.400	
$2SO_3^{2-} + 3H_2O + 4e^- = S_2O_3^{2-} + 6OH^-$	−0.576	1 NaOH
$SO_3^{2-} + 3H_2O + 4e^- = S + 6OH^-$	−0.59	1 NaOH
$S_4O_6^{2-} + 2e^- = 2S_2O_3^{2-}$	0.080	
$S_2O_3^{2-} + 6H^+ + 4e^- = 2S + 3H_2O$	0.5	
$SF_4(g) + 4e^- = S + 4F^-$	0.97	
$S_2Cl_2(g) + 2e^- = 2S + 2Cl^-$	1.19	
$S + H^+ + 2e^- = HS^-$	0.287	
$S + 2H^+ + 2e^- = H_2S(aq)$	0.144	
$S + 2H^+ + 2e^- = H_2S(g)$	0.174	
$S + 2e^- = S^{2-}$	−0.407	
Tantalum		
$Ta_2O_5 + 10H^+ + 10e^- = 2Ta + 5H_2O$	−0.81	
$TaF_7^{2-} + 5e^- = Ta + 7F^-$	−0.45	
Technetium		
$TcO_4^- + 4H^+ + 3e^- = TcO_2 + 2H_2O$	0.738	
$TcO_4^- + 2H^+ + e^- = TcO_3 + H_2O$	0.700	
$TcO_4^- + e^- = TcO_4^{2-}$	0.569	
$TcO_4^- + 8H^+ + 7e^- = Tc + 4H_2O$	0.472	
$TcO_4^{2-} + 4H^+ + 2e^- = TcO_2 + 2H_2O$	1.39	
$TcO_2 + 4H^+ + 4e^- = Tc + 2H_2O$	0.272	
$Tc + e^- = Tc^-$	*ca.* −0.5	
Tellurium		
$H_2TeO_4 + 6H^+ + 2e^- = Te^{4+} + 4H_2O$	0.929	
$H_2TeO_4 + 2H^+ + 2e^- = TeO_2(c) + 2H_2O$	1.02	
$TeO_4^{2-} + 2H^+ + 2e^- = TeO_3^{2-} + H_2O$	0.897	
$TeOOH^+ + 3H^+ + 4e^- = Te + 2H_2O$	0.559	
$H_2TeO_3 + 4H^+ + 4e^- = Te + 3H_2O$	0.589	
$TeO_3^{2-} + 6H^+ + 4e^- = Te + 3H_2O$	0.827	
$TeO_3^{2-} + 3H_2O + 4e^- = Te + 6OH^-$	−0.415	
$TeO_2(c) + 4H^+ + 4e^- = Te + 2H_2O$	0.521	
$Te + 2H^+ + 2e^- = H_2Te(aq)$	−0.740	
$Te + H^+ + 2e^- = HTe^-$	−0.817	
$Te^{2-} + 2H^+ + 2e^- = 2HTe^-$	−0.794	
Terbium		
$Tb^{3+} + 3e^- = Tb$	−2.31	
Thallium		
$Tl^{3+} + 2e^- = Tl^+$	1.25	1 $HClO_4$
	0.77	1 HCl
$Tl^{3+} + 3e^- = Tl$	0.72	
$Tl^+ + e^- = Tl$	−0.336	
$TlCl + e^- = Tl + Cl^-$	−0.557	
$TlBr + e^- = Tl + Br^-$	−0.658	
$TlI + e^- = Tl + I^-$	−0.752	
Thorium		
$Th^{4+} + 4e^- = Th$	−1.83	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Thullium		
$Tm^{3+} + 3e^- = Tm$	−2.32	
Tin		
$Sn^{4+} + 2e^- = Sn^{2+}$	0.154	
$SnCl_6^{2-} + 2e^- = SnCl_4^{2-} + 2Cl^-$	0.14	
$SnO_3^{2-} + 6H^+ + 2e^- = Sn^{2+} + 3H_2O$	0.849	
$SnF_6^{2-} + 4e^- = Sn + 6F^-$	−0.200	
$Sn^{2+} + 2e^- = Sn$	−0.1375	
$SnCl_4^{2-} + 2e^- = Sn + 4Cl^-$	−0.19	1 HCl
$HSnO_2^- + H_2O + 2e^- = Sn + 3OH^-$	−0.91	
$Sn + 4H^+ + 4e^- = SnH_4$	−1.07	
Titanium		
$TiO^{2+} + 2H^+ + e^- = Ti^{3+} + H_2O$	−0.10	
$TiO^{2+} + 2H^+ + 4e^- = Ti + H_2O$	−0.86	
$Ti^{3+} + e^- = Ti^{2+}$	−0.37	
$Ti^{3+} + 3e^- = Ti$	−1.21	
$Ti^{2+} + 2e^- = Ti$	−1.63	
Tungsten		
$2WO_3 + 2H^+ + 2e^- = W_2O_5 + H_2O$	−0.029	
$WO_3 + 6H^+ + 6e^- = W + 3H_2O$	−0.090	
$WO_4^{2-} + 4H_2O + 6e^- = W + 8OH^-$	−1.074	
$WO_4^{2-} + 2H_2O + 2e^- = WO_2 + 4OH^-$	−1.259	
$W_2O_5 + 2H^+ + 2e^- = 2WO_2 + H_2O$	−0.031	
$W(CN)_8^{3-} + e^- = W(CN)_8^{4-}$	0.457	
$WO_2 + 4H^+ + 4e^- = W + 2H_2O$	−0.119	
$WO_2 + 2H_2O + 4e^- = W + 4OH^-$	−0.982	
Uranium		
$UO_2^{2+} + e^- = UO_2^+$	0.16	
$UO_2^{2+} + 4H^+ + 2e^- = U^{4+} + 2H_2O$	0.27	
$UO_2^+ + 4H^+ + e^- = U^{4+} + 2H_2O$	0.38	
$U^{4+} + e^- = U^{3+}$	−0.52	
$U^{4+} + 4e^- = U$	−1.38	
$U^{3+} + 3e^- = U$	−1.66	
Vanadium		
$VO_2^+ + 2H^+ + e^- = VO^{2+} + H_2O$	1.000	
$VO_2^+ + 4H^+ + 2e^- = V^{3+} + 2H_2O$	0.668	
$VO_2^+ + 4H^+ + 3e^- = V^{2+} + 2H_2O$	0.361	
$VO_2^+ + 4H^+ + 5e^- = V + 4H_2O$	−0.236	
$VO^{2+} + 2H^+ + e^- = V^{3+} + H_2O$	0.337	
$V^{3+} + e^- = V^{2+}$	−0.255	
$V^{2+} + 2e^- = V$	−1.13	
Xenon		
$H_4XeO_6 + 2H^+ + 2e^- = XeO_3 + 3H_2O$	2.42	
$HXeO_6^{3-} + 2H_2O + e^- = HXeO_4 + 4OH^-$	0.9	
$XeO_3 + 6H^+ + 2F^- + 4e^- = XeF_2 + 3H_2O$	1.6	
$XeO_3 + 6H^+ + 6e^- = Xe(g) + 3H_2O$	2.10	
$XeF_2 + e^- = XeF + F^-$	0.9	
$XeF_2 + 2H^+ + 2e^- = Xe(g) + 2HF$	2.64	
$XeF + e^- = Xe(g) + F^-$	3.4	

TABLE 8.27 Potentials of the Elements and Their Compounds at 25°C (*Continued*)

Half-reaction	Standard or formal potential	Solution composition
Ytterbium		
$Yb^{3+} + e^- = Yb^{2+}$	−1.05	
$Yb^{2+} + 2e^- = Yb$	−2.8	
$Yb^{3+} + 3e^- = Yb$	−2.22	
Yttrium		
$Y^{3+} + 3e^- = Y$	−2.37	
Zinc		
$Zn^{2+} + 2e^- = Zn$	−0.7626	
$Zn(NH_3)_4^{2+} + 2e^- = Zn + 4NH_3$	−1.04	
$Zn(CN)_4^{2-} + 2e^- = Zn + 4CN^-$	−1.34	
$Zn(tartrate)_4^{6-} + 2e^- = Zn + 4(tartrate)^{2-}$	−1.15	
$Zn(OH)_4^{2-} + 2e^- = Zn + 4OH^-$	−1.285	
Zirconium		
$Zr^{4+} + 4e^- = Zr$	−1.55	
$ZrO_2 + 4H^+ + 4e^- = Zr + 2H_2O$	−1.45	

TABLE 8.28 Potentials of Selected Half-Reactions at 25°C

A summary of oxidation-reduction half-reactions arranged in order of decreasing oxidation strength and useful for selecting reagent systems.

Half-reaction	$E°$, volts
$F_2(g) + 2H^+ + 2e^- = 2HF$	3.053
$O_3 + H_2O + 2e^- = O_2 + 2OH^-$	1.246
$O_3 + 2H^+ + 2e^- = O_2 + H_2O$	2.075
$Ag^{2+} + e^- = Ag^+$	1.980
$S_2O_8^{2-} + 2e^- = 2SO_4^{2-}$	1.96
$HN_3 + 3H^+ + 2e^- = NH_4^+ + N_2$	1.96
$H_2O_2 + 2H^+ + 2e^- = 2H_2O$	1.763
$Ce^{4+} + e^- = Ce^{3+}$	1.72
$MnO_4^- + 4H^+ + 3e^- = MnO_2(c) + 2H_2O$	1.70
$2HClO + 2H^+ + 2e^- = Cl_2 + H_2O$	1.630
$2HBrO + 2H^+ + 2e^- = Br_2 + H_2O$	1.604
$H_5IO_6 + H^+ + 2e^- = IO_3^- + 3H_2O$	1.603
$NiO_2 + 4H^+ + 2e^- = Ni^{2+} + 2H_2O$	1.593
Bi_2O_4(bismuthate) $+ 4H^+ + 2e^- = 2BiO^+ + 2H_2O$	1.59
$MnO_4^- + 8H^+ + 5e^- = Mn^{2+} + 4H_2O$	1.51
$2BrO_3^- + 12H^+ + 10e^- = Br_2 + 6H_2O$	1.478
$PbO_2 + 4H^+ + 2e^- = Pb^{2+} + 2H_2O$	1.468
$Cr_2O_7^{2-} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$	1.36
$Cl_2 + 2e^- = 2Cl^-$	1.3583
$2HNO_2 + 4H^+ + 4e^- = N_2O + 3H_2O$	1.297
$N_2H_5^+ + 3H^+ + 2e^- = 2NH_4^+$	1.275
$MnO_2 + 4H^+ + 2e^- = Mn^{2+} + 2H_2O$	1.23
$O_2 + 4H^+ + 4e^- = 2H_2O$	1.229
$ClO_4^- + 2H^+ + 2e^- = ClO_3^- + H_2O$	1.201

TABLE 8.28 Potentials of Selected Half-Reactions at 25°C (*Continued*)

Half-reaction	$E°$, volts
$2IO_3^- + 12H^+ + 10e^- = I_2 + 3H_2O$	1.195
$N_2O_4 + 2H^+ + 2e^- = 2HNO_3$	1.07
$2ICl_2^- + 2e^- = 4Cl^- + I_2$	1.07
$Br_2(1q) + 2e^- = 2Br^-$	1.065
$N_2O_4 + 4H^+ + 4e^- = 2NO + 2H_2O$	1.039
$HNO_2 + H^+ + e^- = NO + H_2O$	0.996
$NO_3^- + 4H^+ + 3e^- = NO + 2H_2O$	0.957
$NO_3^- + 3H^+ + 2e^- = HNO_2 + H_2O$	0.94
$2Hg^{2+} + 2e^- = Hg_2^{2+}$	0.911
$Cu^{2+} + I^- + e^- = CuI$	0.861
$OsO_4(c) + 8H^+ + 8e^- = Os + 4H_2O$	0.84
$Ag^+ + e^- = Ag$	0.7991
$Hg_2^{2+} + 2e^- = 2Hg$	0.7960
$Fe^{3+} + e^- = Fe^{2+}$	0.771
$H_2SeO_3 + 4H^+ + 4e^- = Se + 3H_2O$	0.739
$HN_3 + 11H^+ + 8e^- = 2NH_4^+$	0.695
$O_2 + 2H^+ + 2e^- = H_2O_2$	0.695
$Ag_2SO_4 + 2e^- = 2Ag + SO_4^{2-}$	0.654
$Cu^{2+} + Br^- + e^- = CuBr(c)$	0.654
$Au(SCN)_4^- + 3e^- = Au + 4SCN^-$	0.636
$2HgCl_2 + 2e^- = Hg_2Cl_2(c) + 2Cl^-$	0.63
$Sb_2O_5 + 6H^+ + 4e^- = 2SbO^+ + 3H_2O$	0.605
$H_3AsO_4 + 2H^+ + 2e^- = HAsO_2 + 2H_2O$	0.560
$TeOOH^+ + 3H^+ + 4e^- = Te + 2H_2O$	0.559
$Cu^{2+} + Cl^- + e^- = CuCl(c)$	0.559
$I_3^- + 2e^- = 3I^-$	0.536
$I_2 + 2e^- = 2I^-$	0.536
$Cu^+ + e^- = Cu$	0.53
$4H_2SO_3 + 4H^+ + 6e^- = S_4O_6^{2-} + 6H_2O$	0.507
$Ag_2CrO_4 + 2e^- = 2Ag + CrO_4^{2-}$	0.449
$2H_2SO_3 + 2H^+ + 4e^- = S_2O_3^{2-} + 3H_2O$	0.400
$UO_2^+ + 4H^+ + e^- = U^{4+} + 2H_2O$	0.38
$Fe(CN)_6^{3-} + e^- = Fe(CN)_6^{4-}$	0.361
$Cu^{2+} + 2e^- = Cu$	0.340
$VO^{2+} + 2H^+ + e^- = V^{3+} + H_2O$	0.337
$BiO^+ + 2H^+ + 3e^- = Bi + H_2O$	0.32
$UO_2^{2+} + 4H^+ + 2e^- = U^{4+} + 2H_2O$	0.27
$Hg_2Cl_2(c) + 2e^- = 2Hg + 2Cl^-$	0.2676
$AgCl + e^- = Ag + Cl^-$	0.2223
$SbO^+ + 2H^+ + 3e^- = Sb + H_2O$	0.212
$CuCl_3^{2-} + e^- = Cu + 3Cl^-$	0.178
$SO_4^{2-} + 4H^+ + 2e^- = H_2SO_3 + H_2O$	0.158
$Sn^{4+} + 2e^- = Sn^{2+}$	0.15
$S + 2H^+ + 2e^- = H_2S$	0.144
$Hg_2Br_2(c) + 2e^- = 2Hg + 2Br^-$	0.1392
$CuCl + e^- = Cu + Cl^-$	0.121
$TiO^{2+} + 2H^+ + e^- = Ti^{3+} + H_2O$	0.100
$S_4O_6^{2-} + 2e^- = 2S_2O_3^{2-}$	0.08
$AgBr + e^- = Ag + Br^-$	0.0711
$HCOOH + 2H^+ + 2e^- = HCHO + H_2O$	0.056
$CuBr + e^- = Cu + Br^-$	0.033
$2H^+ + 2e^- = H_2$	0.0000
$Hg_2I_2 + 2e^- = 2Hg + 2I^-$	−0.0405

TABLE 8.28 Potentials of Selected Half-Reactions at 25°C (*Continued*)

Half-reaction	$E°$, volts
$Pb^{2+} + 2e^- = Pb$	−0.125
$Sn^{2+} + 2e^- = Sn$	−0.136
$AgI + e^- = Ag + I^-$	−0.1522
$N_2 + 5H^+ + 4e^- = N_2H_5^+$	−0.225
$V^{3+} + e^- = V^{2+}$	−0.255
$Ni^{2+} + 2e^- = Ni$	−0.257
$Co^{2+} + 2e^- = Co$	−0.277
$Ag(CN)_2^- + e^- = Ag + 2CN^-$	−0.31
$PbSO_4 + 2e^- = Pb + SO_4^{2-}$	−0.3505
$Cd^{2+} + 2e^- = Cd$	−0.4025
$Cr^{3+} + e^- = Cr^{2+}$	−0.424
$Fe^{2+} + 2e^- = Fe$	−0.44
$H_3PO_3 + 2H^+ + 2e^- = HPH_2O_2 + H_2O$	−0.499
$2CO_2 + 2H^+ + 2e^- = H_2C_2O_4$	−0.49
$U^{4+} + e^- = U^{3+}$	−0.52
$Zn^{2+} + 2e^- = Zn$	−0.7626
$Mn^{2+} + 2e^- = Mn$	−1.18
$Al^{3+} + 3e^- = Al$	−1.67
$Mg^{2+} + 2e^- = Mg$	−2.356
$Na^+ + e^- = Na$	−2.714
$K^+ + e^- = K$	−2.925
$Li^+ + e^- = Li$	−3.045
$3N_2 + 2H^+ + 2e^- = 2HN_3$	−3.10

TABLE 8.29 Overpotentials for Common Electrode Reactions at 25°C

The overpotential is defined as the difference between the actual potential of an electrode at a given current density and the reversible electrode potential for the reaction.

Electrode	Current Density, A/cm²					
	0.001	0.01	0.1	0.5	1.0	5.0
	Overpotential, volts					
Liberation of H_2 from 1*M* H_2SO_4						
Ag	0.097	0.13	0.3		0.48	0.69
Al	0.3	0.83	1.00		1.29	
Au	0.017		0.1		0.24	0.33
Bi	0.39	0.4			0.78	0.98
Cd		1.13	1.22		1.25	
Co		0.2				
Cr		0.4				
Cu			0.35		0.48	0.55
Fe		0.56	0.82		1.29	
Graphite	0.002		0.32		0.60	0.73
Hg	0.8	0.93	1.03		1.07	
Ir	0.0026	0.2				
Ni	0.14	0.3			0.56	0.71
Pb	0.40	0.4			0.52	1.06
Pd	0	0.04				
Pt (smooth)	0.0000	0.16	0.29		0.68	
Pt (platinized)	0.0000	0.030	0.041		0.048	0.051
Sb		0.4				
Sn		0.5	1.2			
Ta		0.39	0.4			
Zn	0.48	0.75	1.06		1.23	
Liberation of O_2 from 1*M* KOH						
Ag	0.58	0.73	0.98		1.13	
Au	0.67	0.96	1.24		1.63	
Cu	0.42	0.58	0.66		0.79	
Graphite	0.53	0.90	1.09		1.24	
Ni	0.35	0.52	0.73		0.85	
Pt (smooth)	0.72	0.85	1.28		1.49	
Pt (platinized)	0.40	0.52	0.64		0.77	
Liberation of Cl_2 from saturated NaCl solution						
Graphite			0.25	0.42	0.53	
Platinized Pt	0.006		0.026	0.05		
Smooth Pt	0.008	0.03	0.054	0.161	0.236	
Liberation of Br_2 from saturated NaBr solution						
Graphite		0.002	0.027	0.16	0.33	
Platinized Pt		0.002	0.012	0.069	0.21	
Smooth Pt		0.002	0.006*	0.26	0.38†	
Liberation of I_2 from saturated Nal solution						
Graphite	0.002	0.014	0.097			
Platinized Pt		0.006	0.032		0.196	
Smooth Pt		0.003	0.03	0.12	0.22	

* At 0.23 A/cm². † At 0.72 A/cm².

The overpotential required for the evolution of O_2 from dilute solutions of $HClO_4$, HNO_3, H_3PO_4 or H_2SO_4 onto smooth platinum electrodes is approximately 0.5 V.

TABLE 8.30 Half-Wave Potentials of Inorganic Materials

All values are in volts vs. the saturated calomel electrode.

Element	$E_{1/2}$, volts	Solvent system
Aluminum		
3+	−0.5	0.2*M* acetate, pH 4.5–4.7, plus 0.07% azo dye Pontochrome Violet SW; reduction wave of complexed dye is 0.2 V more negative than that of the free dye.
Antimony		
3+ to 0	−0.15	1*M* HCl
	−0.31(1)	1*M* HNO_3 (or 0.5*M* H_2SO_4)
	−0.8	0.5*M* tartrate, pH 4.5
	−1.0; −1.2	0.5*M* tartrate, pH 9 (waves not distinct)
	−1.26	1*M* NaOH; also anodic wave (3+ to 5+) at −0.45
	−1.32	0.5*M* tartrate plus 0.1*M* NaOH
5+	0.0; −0.257	6*M* HCl. First wave (5+ to 3+) starts at the oxidation potential of Hg; second wave is 3+ to 0.
5+ to 0	−0.35	1*M* HCl plus 4*M* KBr
Arsenic		
3+ to 5+	−0.26	0.5*M* KOH (anodic wave); only suitable wave
3+	−0.8; −1.0	0.1*M* HCl; ill-defined waves
	−0.7; −1.0	0.5*M* H_2SO_4 (or 1*M* HNO_3)
Barium		
2+ to 0	−1.94	0.1*M* $(C_2H_5)_4NI$
Bismuth		
3+ to 0	−0.025(15)	1*M* HNO_3 (or 0.5*M* H_2SO_4)
	−0.09	1*M* HCl
	−0.29	0.5*M* tartrate, pH 4.5
	−0.7	0.5*M* tartrate (pH 9), wave not well-developed
	−1.0	0.5*M* tartrate plus 0.1*M* NaOH, poor wave
Bromine		
5+ to 1−	−1.75	0.1*M* alkali chlorides (or 0.1*M* NaOH)
	0.13	0.05*M* H_2SO_4
0 to 1−	0.0	Wave (anodic) starts at zero; Hg_2Br_2 forms
Br^-	0.1	Oxidation of Hg to form mercury(I) bromide
Cadmium		
2+ to 0	−0.60	0.1*M* KCl, or 0.5*M* H_2SO_4, or 1*M* HNO_3
	−0.64	0.5*M* tartrate at pH 4.5 or 9
	−0.81	1*M* NH_4Cl plus 1*M* NH_3
Calcium		
2+ to 0	−2.22	0.1*M* $(C_2H_5)_4NCl$
	−2.13	0.1*M* $(C_2H_5)_4NCl$ in 80% ethanol
Cerium		
3+ to 0	−1.97	0.02*M* alkali sulfate
Cesium		
1+ to 0	−2.05	0.1*M* $(C_2H_5)_4NOH$ in 50% ethanol
Chlorine		
Cl^-	0.25	Oxidation of Hg to form Hg_2Cl_2
Chromium		
6+ to 3+	−0.85	CrO_4^{2-} to CrO_2^- in 0.1 to 1*M* NaOH
3+ to 0	−0.35; −1.70	1*M* NH_4Cl—NH_3 buffer (pH 8–9); 3+ to 2+ to 0
3+ to 2+	−0.95	0.1*M* pyridine–0.1*M* pyridinium chloride

TABLE 8.30 Half-Wave Potentials of Inorganic Materials (*Continued*)

Element	$E_{1/2}$, volts	Solvent system
2+ to 0	−1.54	1*M* KCl
2+ to 3+	−0.40	1*M* KCl (anodic wave)
Cobalt		
3+ to 0	−0.5; −1.3	1*M* NH_4Cl plus 1*M* NH_3; 3+ to 2+ to 0
2+ to 0	−1.07	0.1*M* pyridine plus pyridinium chloride
	−1.03	Neutral 1*M* potassium thiocyanate
	−1.4	$Co(H_2O)_6^{2+}$ in noncomplexing systems
3+ to 2+	0.0	1*M* sodium oxalate in acetate buffer (pH 5); diffusion current measured between 0 and −0.1 V
Copper		
2+ to 0	0.04	0.1*M* KNO_3, 0.1*M* NH_4ClO_4, or 1*M* Na_2SO_4
	−0.085	0.1*M* $Na_4P_2O_7$ plus 0.2*M* Na acetate, pH 4.5
	−0.09	0.5*M* Na tartrate, pH 4.5
	−0.20	0.1*M* potassium oxalate, pH 5.7 to 10
	−0.22	0.5*M* potassium citrate, pH 7.5
	−0.4	0.5*M* Na tartrate plus 0.1*M* NaOH (pH 12)
	−0.568	0.1*M* KNO_3 plus 1*M* ethylenediamine
2+	0.04; −0.22	1*M* KCl; consecutive waves: 2+ to 1+ to 0
	−0.02; −0.39	0.1*M* KSCN; consecutive waves: 2+ to 1+ to 0
	0.05; −0.25	0.1*M* pyridine plus 0.1*M* pyridinium chloride; consecutive waves: 2+ to 1+ to 0
	−0.24; −0.50	1*M* NH_4Cl plus 1*M* NH_3; consecutive waves
Gallium		
3+ to 0	−1.1	Not more than 0.001*M* HCl or wave masked by hydrogen wave which immediately follows
Germanium		
2+ to 0	−0.45	6*M* HCl; prior reduction with HPH_2O_2 to 2+
Gold		
3+ to 1+	0	1*M* KCN; wave starts at 0 V
1+ to 0	−1.4	$Au(CN)_2^-$ wave best for analytical purposes
Indium		
3+ to 0	−0.60	1*M* KCl
		In Na acetate, pH 3.9 to 4.2
Iodine		
IO_4^-	0.36	First wave at pH 0 (shifts to −0.08 at pH 12); second wave corresponds to iodate reduction
IO_3^-	−0.075	0.2*M* KNO_3 (shifts −0.13 V/pH unit increase)
	−0.305	0.1*M* hydrogen phthalate, pH 3.2
	−0.500	0.1*M* acetate plus 0.1*M* KCl, pH 4.9
	−0.650	0.1*M* citrate, pH 5.95
	−1.050	0.2*M* phosphate, pH 7.10
	−1.20	0.05*M* borax + 0.1*M* KCl, pH 9.2; or NaOH plus 0.1*M* KCl, pH 13.0
0 to 1−	0.0	Wave starts from zero in acid media; Hg_2I_2 formed
1−	−0.1	Oxidation of Hg to form Hg_2I_2
Iron		
3+	−0.44; −1.52	1*M* $(NH_4)_2CO_3$; two waves; 3+ to 2+ to 0
	−0.17; −1.50	0.5*M* Na tartrate, pH 5.8; two waves; 3+ to 2+ to 0
	−0.9; −1.5	0.1 to 5*M* KOH plus 8% mannitol; 3+ to 2+ to 0

TABLE 8.30 Half-Wave Potentials of Inorganic Materials (*Continued*)

Element	$E_{1/2}$, volts	Solvent system
3+ to 2+	−0.13	0.1*M* EDTA plus 2*M* Na acetate, pH 6–7
	−0.27	0.2*M* Na oxalate, pH 7.9 or less
	−0.28	0.5*M* Na citrate, pH 6.5
	−1.46(2)	1*M* NH_4ClO_4
	−1.36	0.1*M* KHF_2, pH 4 or less
2+ to 3+	−0.28	0.5*M* Na citrate, pH 6.5
	−0.27	0.2*M* Na oxalate, pH 7.9 or less
	−0.17	0.5*M* Na tartrate, pH 5.8
	−1.36	0.1*M* KHF_2, pH 4 or less
Lead		
2+ to 0	−0.405	1*M* HNO_3
	−0.435	1*M* KCl (or HCl)
	−0.49(1)	0.5*M* Na tartrate, pH 4.5 or 9
	−0.72	1*M* KCN
	−0.75	1*M* KOH or 0.5*M* Na tartrate plus 0.1*M* NaOH
Lithium		
1+ to 0	−2.31	0.1*M* $(C_2H_5)_4$ NOH in 50% ethanol
Magnesium		
2+ to 0	−2.2	0.1*M* $(C_2H_5)_4NCl$ (poorly defined wave)
Manganese		
2+ to 0	−1.65	1*M* NH_4Cl plus 1*M* NH_3
	−1.55	1*M* KCNS
	−1.33	1.5*M* KCN
Molybdenum		
6+	−0.26; −0.63	0.3*M* HCl, two waves: 6+ to 5+ to 3+
Nickel		
2+ to 0	−0.70	1*M* KSCN
	−0.78	1*M* KCl plus 0.5*M* pyridine
	−1.09	1*M* NH_4Cl plus 1*M* NH_3
	−1.1	$Ni(H_2O)_6^{2+}$ in NH_4ClO_4 or KNO_3
	−1.36	$Ni(CN)_4^{2-}$ in 1*M* KCN (alkaline media)
Niobium		
5+ to 3+	−0.80(4)	1*M* HNO_3
Nitrogen		
Nitrate	−1.45	0.017*M* $LaCl_3$ (reduced to hydroxylamine)
HNO_2	−0.77	0.1*M* HCl
C_2N_2	−1.2; −1.55	0.1*M* Na acetate, two waves
Oxamic acid	−1.55	0.1*M* Na acetate
Cyanide	−0.45	0.1*M* NaOH; anodic wave starts at −0.45
Thiocyanate	0.18	Anodic wave; neutral or weakly alkaline medium
Osmium		
OsO_4	0.0; −0.41; −1.16	Sat'd $Ca(OH)_2$. Three waves: first starts at 0; second wave is OsO_4^{2-} to Os(V); and third wave is Os(V) to Os(III)
Oxygen		
O_2	−0.05; −0.9	Buffer solutions of pH 1 to 10. Two waves: O_2 to H_2O_2, and H_2O_2 to H_2O. Second wave extends from −0.5 to −1.3
H_2O_2	−0.9	Very extended wave (see above); sharper in presence of Aerosol OT

TABLE 8.30 Half-Wave Potentials of Inorganic Materials (*Continued*)

Element	$E_{1/2}$, volts	Solvent system
Palladium		
2+ to 0	−0.31	1*M* pyridine plus 1*M* KCl
	−0.64	0.1*M* ethylenediamine plus 1*M* KCl
	−0.72	1*M* NH_4Cl plus 1*M* NH_3
Potassium		
1+ to 0	−2.10	0.1*M* $(C_2H_5)_4NOH$ in 50% ethanol
Rhenium		
7+ to 4+	−0.44	2*M* HCl or (better) 4*M* $HClO_4$
4+ to 3+	−0.51	$ReCl_6^{2-}$ ion in 1*M* HCl
Rhodium		
3+ to 2+	−0.41	1*M* pyridine plus 1*M* KCl
Rubidium		
1+ to 0	−1.99	0.1*M* $(C_2H_5)_4NOH$ in 50% ethanol
Scandium		
3+ to 0	−1.80	0.1*M* LiCl, KCl, or $BaCl_2$
Selenium		
4+ to 2−	−1.44	1*M* NH_4Cl plus NH_3, pH 8.0
	−1.54	Same system adjusted to pH 9.5
2−	−0.49	Anodic wave at pH 0 due to HgSe
	−0.94	Anodic wave at pH 12 (0.01*M* NaOH)
Silver		
1+ to 0		Wave starts at oxidation potential of Hg
1+ to 0	−0.3	0.0014*M* $KAg(CN)_2$ without excess cyanide
Sodium		
1+ to 0	−2.07	0.1*M* $(C_2H_5)_4NOH$ in 50% ethanol
Strontium		
2+ to 0	−2.11	0.1*M* $(C_2H_5)_4NI$, water or 80% ethanol
Sulfur		
SO_2	−0.38	1*M* HNO_3 (or other strong acid); 4+ to 2+
$S_2O_4^{2-}$	−0.43	0.5*M* $(NH_4)_2HPO_4$ plus 1*M* NH_3 (anodic wave)
$S_2O_3^{2-}$	−0.15	1*M* strong acid; anodic mercury wave
0 to 2−	−0.50	90% methanol, 9.5% pyridine, 0.5% HCl (pH 6)
HS^-	−0.76	0.1*M* NaOH (anodic mercury wave)
Tellurium		
4+ to 0	−0.4	Citrate buffer, pH 1.6 (second of two waves)
	−0.63	Ammoniacal buffer, pH 9.4
4+ to 2−	−1.22	0.1*M* NaOH
2− to 0	−0.72	1*M* HCl (true anodic reversible wave)
	−0.08	1*M* NaOH (same as above; intermediate values at pH 1 to 13)
Thallium		
3+ to 0	−0.48	1*M* KCl, KNO_3, K_2SO_4, KOH, or NH_3
Tin		
4+ to 2+	−0.25; −0.52	4*M* NH_4Cl + 1*M* HCl; two waves: 4+ to 2+ to 0
2+ to 0	−0.59	0.5*M* tartrate, pH 4.3
	−1.22	1*M* NaOH (stannite ion to tin)
2+ to 4+	−0.28	0.5*M* Na tartrate, pH 4.3 (anodic wave)
	−0.73	1*M* NaOH (stannite ion to stannate ion)

TABLE 8.30 Half-Wave Potentials of Inorganic Materials (*Continued*)

Element	$E_{1/2}$, volts	Solvent system
Titanium		
4+ to 3+	−0.173	0.1*M* $K_2C_2O_4$ plus 1*M* H_2SO_4
	−1.22	0.4*M* tartrate, pH 6.5
Tungsten		
6+	0.0; −0.64	6*M* HCl; two waves: first wave starts at zero and is W(VI) to W(V), the second wave is W(V) to W(III)
Uranium		
6+	−0.180; −0.92	UO_2^{2+} to UO_2^{+}, then U^{3+} in 0.02*M* HCL
Vanadium		
5+ to 4+ to 2+	−0.97; −1.26	1*M* NH_4Cl plus 1*M* NH_3 and 0.08*M* Na_2SO_3
4+ to 2+	−0.98	0.05*M* H_2SO_4
3+ to 2+	−0.55	0.5*M* H_2SO_4
4+ to 5+	−0.32	1*M* NH_4Cl, 1*M* NH_3, and 0.08*M* Na_2SO_3
4+ to 5+	0.76	0.05*M* H_2SO_4; anodic wave starting from zero
2+ to 3+	−0.55	0.5*M* H_2SO_4; anodic wave
Zinc		
2+ to 0	−0.995	0.1*M* KCl
	−1.01	0.1*M* KSCN
	−1.15	0.5*M* tartrate, pH 9
	−1.23	0.5*M* tartrate, pH 4.5
	−1.33	1*M* NH_4Cl plus 1*M* NH_3
	−1.53	1*M* NaOH

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C

The solvent systems in this table are listed below:

A, acetonitrile and a perchlorate salt such as $LiClO_4$ or a tetraalkyl ammonium salt
B, acetic acid and an alkali acetate, often plus a tetraalkyl ammonium iodide
C, 0.05 to 0.175*M* tetraalkyl ammonium halide and 75% 1,4-dioxane
D, buffer plus 50% ethanol (EtOH)

Abbreviations Used in the Table

Bu, butyl	Me, methyl
Et, ethyl	MeOH, methanol
EtOH, ethanol	PrOH, propanol
M, molar	

Compound	Solvent system	$E_{1/2}$
Unsaturated aliphatic hydrocarbons		
Acrylonitrile	C but 30% EtOH	−1.94
Allene	C	−2.29
1,3-Butadiene	A	−2.03
	C	−2.59
1,3-Butadiyne	C	−1.89
1-Buten-2-yne	C	−2.40
1,4-Cyclohexadiene	A	−1.6
Cyclohexene	A	−1.89
1,3,5,7-Cyclooctatetraene	B	−1.42
	C	−1.51
Diethyl fumarate	B, pH 4.0	−0.84
Diethyl maleate	B, pH 4.0	−0.95
2,3-Dimethyl-1,3-butadiene	A	−1.83
Dimethylfulvene	C	−1.89
Diphenylacetylene	C	−2.20
1,1-Diphenylethylene	B	−1.52
	C	−2.19
Ethyl methacrylate	0.1 *N* LiCl+25% EtOH	−1.9
2-Methyl-1,3-butadiene	A	−1.84
2-Methyl-1-butene	A	−1.97
1-Piperidino-4-cyano-4-phenyl-1,3-butadiene	$LiClO_4$ in dimethylformamide	−0.16
trans-Stilbene	B	−1.51
Tetrakis(dimethylamino)ethylene	A	−0.75
Aromatic hydrocarbons		
Acenaphthene	A	−0.95
	B	−1.36
	C	−2.58
Anthracene	A	−0.84
	B	−1.20
	C	−1.94
Azulene	A	−0.71
	C	−1.66, −2.26, −2.56

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
Aromatic hydrocarbons (*continued*)		
1,2-Benzanthracene	C	−2.03, −2.54
2,3-Benzanthracene	A	−0.54, −1.20
Benzene	A	−2.08
1,2-Benzo[*a*]pyrene	A	−0.76
Biphenyl	A	−1.48
	B	−1.91
	C	−2.70
Chrysene	A	−1.22
1,2,5,6-Dibenzanthracene	A	−1.00, −1.26
1,2-Dihydronaphthalene	C	−2.57
9,10-Dimethylanthracene	A	−0.65
2,3-Dimethylnaphthalene	A	−1.08, −1.34
9,10-Diphenylanthracene	A	−0.92
Fluorene	A	−1.25
	B	−1.65
	C	−2.65
Hexamethylbenzene	A	−1.16
	B	−1.52
Indan	A	−1.59, −2.02
Indene	A	−1.23
	C	−2.81
1-Methylnaphthalene	A	−1.24
	B	−1.53
	C	−2.46
2-Methylnaphthalene	A	−1.22
	B	−1.55
	C	−2.46
Naphthalene	A	−1.34
	B	−1.72
Pentamethylbenzene	A	−1.28
	B	−1.62
Phenanthrene	A	−1.23
	B	−1.68
	C	−2.46, −2.71
Phenylacetylene	C	−2.37
Pyrene	A	−1.06, −1.24
trans-Stilbene	B	−1.51
	C	−2.26
Styrene	C	−2.35
1,2,3,5-Tetramethylbenzene	A	−1.50, −1.99
1,2,4,5-Tetramethylbenzene	A	−1.29
Tetraphenylethylene	C	−2.05
1,4,5,8-Tetraphenylnaphthalene	A	−1.39
Toluene	A	−1.98
1,2,3-Trimethylbenzene	A	−1.58
1,2,4-Trimethylbenzene	A	−1.41

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
	Aromatic hydrocarbons (*continued*)	
1,3,5-Trimethylbenzene	A	−1.50
	B	−1.90
Triphenylene	A	−1.46, −1.55
Triphenylmethane	C	−1.01, −1.68, −1.96
o-Xylene	A	−1.58, −2.04
m-Xylene	A	−1.58
p-Xylene	A	−1.56
	Aldehydes	
Acetaldehyde	B, pH 6.8–13	−1.89
Benzaldehyde	McIlvaine buffer, pH 2.2	−0.96, −1.32
Bromoacetaldehyde	pH 8.5	−0.40
	pH 9.8	−1.58, −1.82
Chloroacetaldehyde	Ammonia buffer, pH 8.4	−1.06, −1.66
Cinnamaldehyde	Buffer + EtOH, pH 6.0	−0.9, −1.5, −1.7
Crotonaldehyde	B, pH 1.3–2.0	−0.92
	Ammonia buffer, pH 8.0	−1.30
Dichloroacetaldehyde	Ammonia buffer, pH 8.4	−1.03, −1.67
3,7-Dimethyl-2,6-octadienal	0.1 *M* Et_4NI	−1.56, −2.22
Formaldehyde	0.05 *M* KOH+0.1 *M* KCl, pH 12.7	−1.59
2-Furaldehyde	pH 1–8	−0.86–0.07 pH
	pH 10	−1.43
Glucose	Phosphate buffer, pH 7	−1.55
Glyceraldehyde	Britton-Robinson buffer, pH 5.0	−1.47
	Britton-Robinson buffer, pH 8.0	−1.55
Glycolaldehyde	0.1 *M* KOH, pH 13	−1.70
Glyoxal	B, pH 3.4	−1.41
4-Hydroxybenzaldehyde	Britton-Robinson buffer, pH 1.8	−1.16
	Britton-Robinson buffer, pH 6.8	−1.45
4-Hydroxy-2-methoxybenzaldehyde	McIlvaine buffer, pH 2.2	−1.05
	McIlvaine buffer, pH 5.0	−1.16, −1.36
	McIlvaine buffer, pH 8.0	−1.47
o-Methoxybenzaldehyde	Britton-Robinson buffer, pH 1.8	−1.02
	Britton-Robinson buffer, pH 6.8	−1.49
p-Methoxybenzaldehyde	Britton-Robinson buffer, pH 1.8	−1.17
	Britton-Robinson buffer, pH 6.8	−1.48
Methyl glyoxal	A, pH 4.5	−0.83
m-Nitrobenzaldehyde	Buffer+10% EtOH, pH 2.0	−0.28, −1.20
Phthalaldehyde	Buffer, pH 3.1	−0.64, −1.07
	Buffer, pH 7.3	−0.89, −1.29
2-Propenal (acrolein)	pH 4.5	−1.36
	pH 9.0	−1.1
Propionaldehyde	0.1 *M* LiOH, pH 13	−1.93
Pyrrole-2-carbaldehyde	0.1 *M* HCl+50% EtOH	−1.25

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
	Aldehydes (*continued*)	
Salicylaldehyde	McIlvaine buffer, pH 2.2	−0.99, −1.23
	McIlvaine buffer, pH 5.0	−1.20, −1.30
	McIlvaine buffer, pH 8.0	−1.32
Trichloroacetaldehyde	Ammonia buffer, pH 8.4	−1.35, −1.66
	0.1 *M* KCl+50% EtOH	−1.55
	Ketones	
Acetone	B, pH 9.3	−1.52
	C	−2.46
Acetophenone	D+McIlvaine buffer, pH 4.9	−1.33
	D+McIlvaine buffer, pH 7.2	−1.58
	D+McIlvaine buffer, pH 1.3	−1.08
7*H*-Benz[*de*]anthracen-7-one	0.1 *N* H_2SO_4+75% MeOH	−0.96
Benzil	D+McIlvaine buffer, pH 1.3	−0.27
	D+McIlvaine buffer, pH 4.9	−0.50
Benzoin	D+McIlvaine buffer, pH 1.3	−0.90
	D+McIlvaine buffer, pH 8.6	−1.49
Benzophenone	D+McIlvaine buffer, pH 1.3	−0.94
	D+McIlvaine buffer, pH 8.6	−1.36
Benzoylacetone	Buffer, pH 2.6	−1.60
	Buffer, pH 5.3 and pH 7.6	−1.68
	Buffer, pH 9.7	−1.72
Bromoacetone	0.1 *M* LiCl	−0.29
2,3-Butanedione	0.1 *M* HCl	−0.84
3-Buten-2-one	0.1 *M* KCl	−1.42
Butyrophenone	0.1 *M* NH_4Cl+50% EtOH	−1.55
D-Carvone	0.1 *M* Et_4NI+80% EtOH	−1.71
Chloroacetone	0.1 *M* LiCl	−1.18
Coumarin	McIlvaine buffer, pH 2.0	−0.95
	McIlvaine buffer, pH 5.0	−1.11, −1.44
Cyclohexanone	C	−2.45
cis-Dibenzoylethylene	D, pH 1	−0.30
	D, pH 11	−0.62, −1.65
trans-Dibenzoylethylene	D, pH 1	−0.12
	D, pH 11	−0.57, −1.52
Dibenzoylmethane	D, pH 1.3	−0.59
	D, pH 11.3	−1.30, −1.62
9,10-Dihydro-9-oxoanthracene	D, pH 2.0	−0.93
1,5-Diphenyl-1,5-pentanedione	A	−2.10
1,5-Diphenylthiocarbazone	D, pH 7.0	−0.6
Flavanone	Acetate buffer+Me_4NOH+50% 2-PrOH, pH 6.1	−1.30
	Acetate buffer+Me_4NOH+50% 2-PrOH, pH 9.6	−1.51
Fluorescein	Acetate buffer, pH 2.0	−0.50
	Phthalate buffer, pH 5.0	−0.65
	Borate buffer, pH 10.1	−1.18, −1.44
Fructose	0.02 *M* LiCl	−1.76

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
	Ketones (*continued*)	
Girard derivatives of aliphatic ketones	pH 8.2	−1.52
o-Hydroxyacetophenone	D, pH 5	−1.36
p-Hydroxyacetophenone	D, pH 5	−1.46
1,2,3-Indantrione (ninhydrin)	Britton-Robinson buffer, pH 2.5	−0.67, −0.83
	Britton-Robinson buffer, pH 4.5	−0.73, −1.01
	Britton-Robinson buffer, pH 6.8	−0.10, −0.90, −1.20
	Britton-Robinson buffer, pH 9.2	−1.35
α-Ionone	C	−1.59, −2.08
Isatin	Phosphate buffer+citrate buffer, pH 2.9	−0.3, −0.5
	Phosphate buffer+citrate buffer, pH 4.3	−0.3, −0.5, −0.8
	Phosphate buffer+citrate buffer, pH 5.4	−0.8
4-Methyl-3,5-heptadien-2-one	A	−0.64
4-Methyl-2,6-heptanedione	A	−1.28
4-Methyl-3-penten-2-one	D+McIlvaine buffer, pH 1.3	−1.01
	D+McIlvaine buffer, pH 11.3	−1.60
4-Phenyl-3-buten-2-one	D, pH 1.3	−0.72
	D, pH 8.6	−1.27
Phthalide	0.1 *M* Bu_4NI+50% dioxane	−0.20
Phthalimide	pH 4.2	−1.1, −1.5
	pH 9.7	−1.2, −1.4
Pulegone	C	−1.74
Quinalizarin	Phosphate buffer+1% EtOH, pH 8.0	−0.56
Testosterone	D+Britton-Robinson buffer, pH 2.6	−1.20
	D+Britton-Robinson buffer, pH 5.8	−1.40
	D+Britton-Robinson buffer, pH 8.8	−1.53, −1.79
	Quinones	
Anthraquinone	Acetate buffer+40% dioxane, pH 5.6	−0.51
	Phosphate buffer+40% dioxane, pH 7.9	−0.71
o-Benzoquinone	Britton-Robinson buffer, pH 7.0	+0.20
	Britton-Robinson buffer, pH 9.0	+0.08
2,3-Dimethylnaphthoquinone	D, pH 5.4	−0.22
1,2-Naphthoquinone	Phosphate buffer, pH 5.0	−0.03
	Phosphate buffer, pH 7.0	−0.13
1,4-Naphthoquinone	Britton-Robinson buffer, pH 7.0	−0.07
	Britton-Robinson buffer, pH 9.0	−0.19

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
	Acids	
Acetic acid	A	−2.3
Acrylic acid	pH 5.6	−0.85
Adenosine-5′-phosphoric acid	$HClO_4$+$KClO_4$, pH 2.2	−1.13
4-Aminobenzenesulfonic acid	0.05 *M* Me_4NI	−1.58
3-Aminobenzoic acid	pH 5.6	−0.67
Anthranilic acid	pH 5.6	−0.67
Ascorbic acid	Britton-Robinson buffer, pH 3.4	+0.17
	Britton-Robinson buffer, pH 7.0	−0.06
Barbituric acid	Borate buffer, pH 9.3	−0.04
Benzoic acid	A	−2.1
Benzoylformic acid	Britton-Robinson buffer, pH 2.2	−0.48
	Britton-Robinson buffer, pH 5.5	−0.85, −1.26
	Britton-Robinson buffer, pH 7.2	−0.98, −1.25
	Britton-Robinson buffer, pH 9.2	−1.25
Bromoacetic acid	pH 1.1	−0.54
2-Bromopropionic acid	pH 2.0	−0.39
Crotonic acid	C	−1.94
Dibromoacetic acid	pH 1.1	−0.03, −0.59
Dichloroacetic acid	pH 8.2	−1.57
5,5-Diethylbarbituric acid	Borate buffer, pH 9.3	0.00
Flavanol	D, pH 5.6	−1.25
	D, pH 7.7	−1.40
Folic acid	Britton-Robinson buffer, pH 4.6	−0.73
Formic acid	0.1 *M* KCl	−1.66
Fumaric acid	HCl+KCl, pH 2.6	−0.83
	Acetate buffer, pH 4.0	−0.93
	Acetate buffer, pH 5.9	−1.20
2,4-Hexadienedioic acid	Acetate buffer, pH 4.5	−0.97
Iodoacetic acid	pH 1	−0.16
Maleic acid	Britton-Robinson buffer, pH 2.0	−0.70
	Britton-Robinson buffer, pH 4.0	−0.97
	Britton-Robinson buffer, pH 6.0	−1.11, −1.30
	Britton-Robinson buffer, pH 10.0	−1.51
Mercaptoacetic acid	B, pH 6.8	−0.38
Methacrylic acid	D+0.1 *M* LiCl	−1.69
Nitrobenzoic acids	Buffer+10% EtOH, pH 2.0	−0.2, −0.7
Oxalic acid	B, pH 5.4–6.1	−1.80
2-Oxo-1,5-pentanedioic acid	HCl+KCl, pH 1.8	−0.59
	Ammonia buffer, pH 8.2	−1.30
2-Oxopropionic acid	Britton-Robinson buffer, pH 5.6	−1.17
	Britton-Robinson buffer, pH 6.8	−1.22, −1.53
	Britton-Robinson buffer, pH 9.7	−1.51
Phenolphthalein	Phthalate buffer, pH 2.5	−0.67
	Phthalate buffer, pH 4.7	−0.80
	D, pH 9.6	−0.98, −1.35
Picric acid	pH 4.2	−0.34
	pH 11.7	−0.36, −0.56, −0.96

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
	Acids (*continued*)	
1,2,3-Propenetricarboxylic acid	pH 7.0	−2.1
Trichloroacetic acid	Ammonia buffer, pH 8.2	−0.84, −1.57
	Phosphate buffer, pH 10.4	−0.9, −1.6
3,4,5-Trihydroxybenzoic acid	Phosphate buffer, pH 2.9	+0.50
	Phosphate buffer, pH 8.8	+0.1
p-Aminophenol	Britton-Robinson buffer, pH 6.3	+0.14
	Britton-Robinson buffer, pH 8.6	−0.04
	Britton-Robinson buffer, pH 12.0	−0.16
o-Chlorophenol	pH 5.6	−0.63
m-Chlorophenol	pH 5.6	−0.73
p-Chlorophenol	pH 5.6	−0.65
o-Cresol	pH 5.6	−0.56
m-Cresol	pH 5.6	−0.61
p-Cresol	pH 5.6	−0.54
1,2-Dihydroxybenzene	pH 5.6	−0.35
1,3-Dihydroxybenzene	pH 5.6	−0.61
1,4-Dihydroxybenzene	pH 5.6	−0.23
o-Methoxyphenol	pH 5.6	−0.46
m-Methoxyphenol	pH 5.6	−0.62
p-Methoxyphenol	pH 5.6	−0.41
1-Naphthol	A	−0.74
2-Naphthol	A	−0.82
1,2,3-Trihydroxybenzene	Britton-Robinson buffer, pH 3.1	+0.35
	Britton-Robinson buffer, pH 6.5	+0.10
	Britton-Robinson buffer, pH 9.5	−0.10
	Halogen compounds	
Bromobenzene	A	−1.98
	C	−2.32
1-Bromobutane	C	−2.27
Bromoethane	C	−2.08
Bromomethane	C	−1.63
1-Bromonaphthalene (also 2-bromonaphthalene)	A	−1.55, −1.60
3-Bromo-1-propene	C	−1.29
p-Bromotoluene	A	−1.72
Carbon tetrachloride	C	−0.78, −1.71
Chlorobenzene	A	−2.07
Chloroform	C	−1.63
Chloromethane	C	−2.23
3-Chloro-1-propene	C	−1.91
α-Chlorotoluene	C	−1.81
p-Chlorotoluene	A	−1.76
N-Chloro-*p*-toluenesulfonamide	0.5 *M* K_2SO_4	−0.13
9,10-Dibromoanthracene	A	−1.15, −1.47
p-Dibromobenzene	C	−2.10
1,2-Dibromobutane	D+1% Na_2SO_3	−1.45

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
Halogen compounds (*continued*)		
Dibromoethane	C	−1.48
meso-2,3-Dibromosuccinic acid	Acetate buffer, pH 4.0	−0.23, −0.89
Dichlorobenzenes	C	−2.5
Dichloromethane	C	−1.60
Diiodomethane	C	−1.12, −1.53
Hexabromobenzene	C	−0.8, −1.5
Hexachlorobenzene	C	−1.4, −1.7
Iodobenzene	A	−1.72
Iodoethane	C	−1.67
Iodomethane	A	−2.12
	C	−1.63
Tetrabromomethane	C	−0.3, −0.75, −1.49
Tetraidomethane	C	−0.45, −1.05, −1.46
Tribromomethane	C	−0.64, −1.47
α,α,α-Trichlorotoluene	C	−0.68, −1.65, −2.00
Nitro and nitroso compounds		
1,2-Dinitrobenzene	Phthalate buffer, pH 2.5	−0.12, −0.32, −1.26
	Borate buffer, pH 9.2	−0.38, −0.74
1,3-Dinitrobenzene	Phthalate buffer, pH 2.5	−0.17, −0.29
	Borate buffer, pH 9.2	−0.46, −0.68
1,4-Dinitrobenzene	Phthalate buffer, pH 2.5	−0.12, −0.33
	Borate buffer, pH 9.2	−0.35, −0.80
Methyl nitrobenzoates	Buffer+10% EtOH, pH 2.0	−0.20 to −0.25 −0.68 to −0.74
p-Nitroacetophenone	Britton-Robinson buffer, pH 2.2	−0.16, −0.61, −1.09
	Britton-Robinson buffer, pH 10.0	−0.51, −1.40, −1.73
o-Nitroaniline	0.03 *M* LiCl+0.02 *M* benzoic acid in EtOH	−0.88
m-Nitroaniline	Britton-Robinson buffer, pH 4.3	−0.3, −0.8
	Britton-Robinson buffer, pH 7.2	−0.5
	Britton-Robinson buffer, pH 9.2	−0.7
p-Nitroaniline	pH 2.0	−0.36
	Acetate buffer, pH 4.6	−0.5
o-Nitroanisole	Buffer+10% EtOH, pH 2.0	−0.29, −0.58
p-Nitroanisole	Buffer+10% EtOH, pH 2.0	−0.35, −0.64
1-Nitroanthraquinone	Britton-Robinson buffer, pH 7.0	−0.16
Nitrobenzene	HCl+KCl+8% EtOH, pH 0.5	−0.16, −0.76
	Phthalate buffer, pH 2.5	−0.30
	Borate buffer, pH 9.2	−0.70
Nitrocresols	Britton-Robinson buffer, pH 2.2	−0.2 to −0.3
	Britton-Robinson buffer, pH 4.5	−0.4 to −0.5
	Britton-Robinson buffer, pH 8.0	−0.6
Nitroethane	Britton-Robinson buffer+30% MeOH, pH 1.8	−0.7
	Britton-Robinson buffer+30% MeOH, pH 4.6	−0.8

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
Nitro and nitroso compounds (*continued*)		
2-Nitrohydroquinone	Phosphate buffer+citrate buffer, pH 2.1	−0.2
	Phosphate buffer+citrate buffer, pH 5.2	−0.4
	Phosphate buffer+citrate buffer, pH 8.0	−0.5
Nitromethane	Britton-Robinson buffer+30% MeOH, pH 1.8	−0.8
	Britton-Robinson buffer+30% MeOH, pH 4.6	−0.85
o-Nitrophenol	Britton-Robinson buffer+10% EtOH, pH 2.0	−0.23
	Britton-Robinson buffer+10% EtOH, pH 4.0	−0.4
	Britton-Robinson buffer+10% EtOH, pH 8.0	−0.65
	Britton-Robinson buffer+10% EtOH, pH 10.0	−0.80
m-Nitrophenol	Britton-Robinson buffer+10% EtOH, pH 2.0	−0.37
	Britton-Robinson buffer+10% EtOH, pH 4.0	−0.40
	Britton-Robinson buffer+10% EtOH, pH 8.0	−0.64
	Britton-Robinson buffer+10% EtOH, pH 10.0	−0.76
p-Nitrophenol	Britton-Robinson buffer+10% EtOH, pH 2.0	−0.35
	Britton-Robinson buffer+10% EtOH, pH 4.0	−0.50
	Britton-Robinson buffer+10% EtOH, pH 8.0	−0.82
1-Nitropropane	Britton-Robinson buffer+30% MeOH, pH 1.8	−0.73
	Britton-Robinson buffer+30% MeOH, pH 8.6	−0.88
	Britton-Robinson buffer+30% MeOH, pH 8.0	−0.95
2-Nitropropane	McIlvaine buffer, pH 2.1	−0.53
	McIlvaine buffer, pH 5.1	−0.81
Nitrosobenzene	McIlvaine buffer, pH 6.0	−0.03
	McIlvaine buffer, pH 8.0	−0.14
1-Nitroso-2-naphthol	D+buffer, pH 4.0	+0.02
	D+buffer, pH 7.0	−0.20
	D+buffer, pH 9.0	−0.31
N-Nitrosophenylhydroxylamine	pH 2.0	−0.84
o-Nitrotoluene	Phthalate buffer, pH 2.5	−0.35, −0.66
	Phthalate buffer, pH 7.4	−0.60, −1.06

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
Nitro and nitroso compounds (*continued*)		
m-Nitrotoluene (also *p*-nitrotoluene)	Phthalate buffer, pH 2.5	−0.30, −0.53
	Phthalate buffer, pH 7.4	−0.58, −1.06
Tetranitromethane	pH 12.0	−0.41
1,3,5-Trinitrobenzene	Phthalate buffer, pH 4.1	−0.20, −0.29, −0.34
	Borate buffer, pH 9.2	−0.34, −0.48, −0.65
Heterocyclic compounds containing nitrogen		
Acridine	D, pH 8.3	−0.80, −1.45
Cinchonine	B, pH 3	−0.90
2-Furanmethanol	Britton-Robinson buffer, pH 2.0	−0.96
	Britton-Robinson buffer, pH 5.8	−1.38, −1.70
2-Hydroxyphenazine	Britton-Robinson buffer, pH 4.0	−0.24
8-Hydroxyquinoline	B, pH 5.0	−1.12
	Phosphate buffer, pH 8.0	−1.18, −1.71
3-Methylpyridine	D+0.1 *M* LiCl	−1.76
4-Methylpyridine	D+0.1 *M* LiCl	−1.87
Phenazine	Phosphate buffer+citrate buffer, pH 7.0	−0.36
Pyridine	Phosphate buffer+citrate buffer, pH 7.0	−1.75
Pyridine-2-carboxylic acid	B, pH 4.1	−1.10
	B, pH 9.3	−1.48, −1.94
Pyridine-3-carboxylic acid	0.1 *M* HCl	−1.08
Pyridine-4-carboxylic acid	Britton-Robinson buffer, pH 6.1	−1.14
	pH 9.0	−1.39, −1.68
Pyrimidine	Citrate buffer, pH 3.6	−0.92, −1.24
	Ammonia buffer, pH 9.2	−1.54
Quinoline-8-carboxylic acid	pH 9	−1.11
Quinoxaline	Phosphate buffer+citrate buffer, pH 7.0	−0.66, −1.52
Azo, hydrazine, hydroxylamine, and oxime compounds		
Azobenzene	D, pH 4.0	−0.20
	D, pH 7.0	−0.50
Azoxybenzene	Buffer+20% EtOH, pH 6.3	−0.30
Benzoin 1-oxime	Buffer, pH 2.0	−0.88
	Buffer, pH 5.6	−1.08
	Buffer, pH 8.2	−1.67
Benzoylhydrazine	0.13 *M* NaOH, pH 13.0	−0.30
Dimethylglyoxime	Ammonia buffer, pH 9.6	−1.63
Hydrazine	Britton-Robinson buffer, pH 9.3	−0.09
Hydroxylamine	Britton-Robinson buffer, pH 4.6	−1.42
	Britton-Robinson buffer, pH 9.2	−1.65

TABLE 8.31 Half-Wave Potentials (vs. Saturated Calomel Electrode) of Organic Compounds at 25°C (*Continued*)

Compound	Solvent system	$E_{1/2}$
Azo, hydrazine, hydroxylamine, and oxime compounds (*continued*)		
Oxamide	Acetate buffer	−1.55
Phenylhydrazine	McIlvaine buffer, pH 2	+0.19
	0.13 *M* NaOH, pH 13.0	−0.36
Phenylhydroxylamine	McIlvaine buffer+10% EtOH, pH 2	−0.68
	McIlvaine buffer+10 EtOH, pH 4–10	−0.33 0.061 pH
Salicylaldoxime	Phosphate buffer, pH 5.4	−1.02
Thiosemicarbazide	Borate buffer, pH 9.3	−0.26
Thiourea	0.1 *M* sulfuric acid	+0.02
Indicators and dyestuffs		
Brilliant Green	HCl+KCl, pH 2.0	−0.2, −0.5
Indigo carmine	pH 2.5	−0.24
Indigo disulfonate	pH 7.0	−0.37
Malachite Green G	HCl+KCl, pH 2.0	−0.2, −0.5
Metanil yellow	Phosphate buffer+1% EtOH, pH 7.0	−0.51
Methylene blue	Britton-Robinson buffer, pH 4.9	−0.15
	Britton-Robinson buffer, pH 9.2	−0.30
Methylene green	Phosphate buffer+1% EtOH, pH 7.0	−0.12
Methyl orange	Phosphate buffer+1% EtOH, pH 7.0	−0.51
Morin	D, pH 7.6	−1.7
Neutral red	Britton-Robinson buffer, pH 2.0	−0.21
	Britton-Robinson buffer, pH 7.0	−0.57
Peroxide		
Ethyl peroxide	0.02 *M* HCl	−0.2

8.7 CONDUCTANCE

TABLE 8.32 Limiting Equivalent Ionic Conductances in Aqueous Solutions

In 10^{-4} $m^2 \cdot S \cdot equiv^{-1}$ or mho $\cdot$ $cm^2 \cdot equiv^{-1}$.

	Temperature, °C		
Ion	0	18	25
Inorganic cations			
Ag^+	33	54.5	61.9
Al^{3+}	29		61
Ba^{2+}	33.6	54.3	63.9
Be^{2+}			45
Ca^{2+}	30.8	51	59.5
Cd^{2+}	28	45.1	54
Ce^{3+}			70
Co^{2+}	28	45	53
$Co(NH_3)_6^{3+}$			100
Co(ethylenediamine)$_3^{3+}$			74.7
Cr^{3+}			67
Cs^+	44	68	77.3
Cu^{2+}	28	45.3	56.6
D^+ (deuterium)		213.7	
Dy^{3+}			65.7
Er^{3+}			66.0
Eu^{3+}			67.9
Fe^{2+}	28	45.3	53.5
Fe^{3+}			69
Gd^{3+}			67.4
H^+	224.1	315.8	350.1
Hg_2^{2+}			68.7
Hg^{2+}			63.6
Ho^{3+}			66.3
K^+	40.3	64.6	73.5
La^{3+}	35.0	59.2	69.6
Li^+	19.1	33.4	38.69
Mg^{2+}	28.5	46	53.06
Mn^{2+}	27	44.5	53.5
NH_4^+	40.3	64	73.7
$N_2H_5^+$ (hydrazinium 1+)			59
Na^+	25.85	43.5	50.11
Nd^{3+}			69.6
Ni^{2+}	28	45	50
Pb^{2+}	37.5	60.5	71
Pr^{3+}			69.6
Ra^{2+}	33	56.6	66.8
Rb^+	43.5	67.5	77.8
Sc^{3+}			64.7
Sm^{3+}			68.5
Sr^{2+}	31	51	59.46
Tl^+	43.3	66	74.9
Tm^{3+}			65.5
UO_2^{2+}			32
Y^{3+}			62
Yb^{3+}			65.2
Zn^{2+}	28	45.0	52.8

TABLE 8.32 Limiting Equivalent Ionic Conductances in Aqueous Solutions (*Continued*)

Ion	Temperature, °C		
	0	18	25
Inorganic anions			
$Au(CN)_2^-$			50
$Au(CN)_4^-$			36
$B(C_6H_5)_4^-$			21
Br^-	43.1	67.6	78.1
Br_3^-			43
BrO_3^-	31.0	49.0	55.7
Cl^-	41.4	65.5	76.31
ClO_2^-			52
ClO_3^-	36	55.0	64.6
ClO_4^-	37.3	59.1	67.3
CN^-			78
CO_3^{2+}	36	60.5	69.3
$Co(CN)_6^{3-}$			98.9
CrO_4^{2-}	42	72	85
F^-		46.6	55.4
$Fe(CN)_6^{4-}$			110.4
$Fe(CN)_6^{3-}$			100.9
$H_2AsO_4^-$			34
HCO_3^-			44.5
HF_2^-			75
HPO_4^{2-}			33
$H_2PO_4^-$		28	33
HS^-	40	57	65
HSO_3^-	27		50
HSO_4^-			50
$H_2SbO_4^-$			31
I^-	42.0	66.5	76.9
IO_3^-	21.0	33.9	40.5
IO_4^-		49	54.5
MnO_4^-	36	53	61.3
MoO_4^{2-}			74.5
N_3^-			69.5
$N(CN)_2^-$			54.5
NO_2^-	44	59	71.8
NO_3^-	40.2	61.7	71.42
$NH_2SO_3^-$ (sulfamate)			48.6
OCN^- (cyanate)		54.8	64.6
OH^-	117.8	175.8	198
PF_6^-			56.9
PO_3F^{2-}			63.3
PO_4^{3-}			69.0
$P_2O_7^{4-}$			96
$P_3O_9^{3-}$			83.6
$P_3O_{10}^{5-}$			109
ReO_4^-		46.5	54.9
SCN^- (thiocyanate)	41.7	56.6	66.5
$SeCN^-$			64.7
SeO_4^{2-}		65	75.7
SO_3^{2-}			79.9

TABLE 8.32 Limiting Equivalent Ionic Conductances in Aqueous Solutions (*Continued*)

Ion	Temperature, °C		
	0	18	25
SO_4^{2-}	41	68.3	80.0
$S_2O_3^{2-}$			85.0
$S_2O_4^{2-}$	34		66.5
$S_2O_6^{2-}$			93
$S_2O_8^{2-}$			86
WO_4^{2-}	35	59	69.4
Organic cations			
Decylpyridinium$^+$			29.5
Diethylammonium$^+$			42.0
Dimethylammonium$^+$			51.5
Dipropylammonium$^+$			30.1
Dodecylammonium$^+$			23.8
Ethylammonium$^+$			47.2
Ethyltrimethylammonium$^+$			40.5
Isobutylammonium$^+$			38.0
Methylammonium$^+$			58.3
Piperidinium$^+$			37.2
Propylammonium$^+$			40.8
Tetrabutylammonium$^+$			19.5
Tetraethylammonium$^+$			32.6
Tetramethylammonium$^+$			44.9
Tetrapropylammonium$^+$			23.5
Triethylsulfonium$^+$			36.1
Trimethylammonium$^+$			47.2
Trimethylsulfonium$^+$			51.4
Tripropylammonium$^+$			26.1
Organic anions			
Acetate$^-$	20	34	41
Benzoate$^-$			32.4
Bromoacetate$^-$			39.2
Bromobenzoate$^-$			30
Butanoate$^-$			32.6
Chloroacetate$^-$			42.2
m-Chlorobenzoate$^-$			31
o-Chlorobenzoate$^-$			30.5
Citrate(3−)			70.2
Crotonate$^-$			33.2
Cyanoacetate$^-$			43.4
Cyclohexanecarboxylate$^-$			28.7
Cyclopropane-1,3-dicarboxylate^{2-}			53.4
Decylsulfonate$^-$			26
Dichloroacetate$^-$			38.3
Diethylbarbiturate(2−)			26.3
Dihydrogencitrate$^-$			30
Dimethylmalonate(2−)			49.4
3,5-Dinitrobenzoate$^-$			28.3
Dodecylsulfonate$^-$			24
Ethylmalonate$^-$			49.3
Ethylsulfonate$^-$			39.6

TABLE 8.32 Limiting Equivalent Ionic Conductances in Aqueous Solutions (*Continued*)

Ion	Temperature, °C		
	0	18	25
Fluoroacetate$^-$			44.4
Fluorobenzoate$^-$			33
Formate$^-$		47	54.6
Fumarate(2−)			61.8
Glutarate(2−)			52.6
Hydrogenoxalate (1−)			40.2
Iodoacetate$^-$			40.6
Lactate(1−)			38.8
Malate(2−)			58.8
Malonate(1−)			63.5
3-Methylbutanoate$^-$			32.7
Methylsulfonate$^-$			48.8
Naphthylacetate$^-$			28.4
1,8-Octanedioate(2−)			36
Octylsulfonate$^-$			29
Oxalate(2−)			74.11
Phenylacetate$^-$			30.6
m-Phthalate(2−)			54.7
o-Phthalate(2−)			52.3
Picrate$^-$			30.37
Propanoate$^-$			35.8
Propylsulfonate$^-$			37.1
Salicylate$^-$			36
Succinate(2−)			58.8
Tartrate(2−)		55	59.6
Trichloroacetate$^-$			36.6
Trimethylacetate$^-$			31.9

TABLE 8.33 Standard Solutions for Calibrating Conductivity Vessels

The values of conductivity κ are corrected for the conductivity of the water used. The cell constant θ of a conductivity cell can be obtained from the equation

$$\theta = \frac{\kappa R R_{\text{solv}}}{R_{\text{solv}} - R}$$

where R is the resistance measured when the cell is filled with a solution of the composition stated in the table below, and R_{solv} is the resistance when the cell is filled with solvent at the same temperature.

Grams KCl per Kilogram Solution (in vacuo)	Conductivity in ohm^{-1} · cm^{-1} at		
	0°C	18°C	25°C
71.135 2	$0.065\ 14_4$	$0.097\ 79_0$	$0.111\ 28_7$
7.419 13	$0.007\ 134_4$	$0.011\ 161_2$	$0.012\ 849_7$
0.745 263*	$0.000\ 773\ 2_6$	$0.001\ 219\ 9_2$	$0.001\ 408\ 0_8$

* Virtually 0.0100 *M*.

From the data of Jones and Bradshaw, *J. Am. Chem. Soc.*, **55,** 1780 (1933). The original data have been converted from (int. ohm)$^{-1}$ cm^{-1}.

TABLE 8.34 Electrical Conductivity of Various Pure Liquids

Liquid	Temp. °C	mhos/cm or $ohm^{-1} \cdot cm^{-1}$
Acetaldehyde	15	1.7×10^{-6}
Acetamide	100	$<4.3 \times 10^{-5}$
Acetic acid	0	5×10^{-9}
	25	1.12×10^{-8}
Acetic anhydride	0	1×10^{-6}
	25	4.8×10^{-7}
Acetone	18	2×10^{-8}
	25	6×10^{-8}
Acetonitrile	20	7×10^{-6}
Acetophenone	25	6×10^{-9}
Acetyl bromide	25	2.4×10^{-6}
Acetyl chloride	25	4×10^{-7}
Alizarin	233	1.45×10^{-6}(?)
Allyl alcohol	25	7×10^{-6}
Ammonia	−79	1.3×10^{-7}
Aniline	25	2.4×10^{-8}
Anthracene	230	3×10^{-10}
Arsenic tribromide	35	1.5×10^{-6}
Arsenic trichloride	25	1.2×10^{-6}
Benzaldehyde	25	1.5×10^{-7}
Benzene	···	7.6×10^{-8}
Benzoic acid	125	3×10^{-9}
Benzonitrile	25	5×10^{-8}
Benzyl alcohol	25	1.8×10^{-6}
Benzylamine	25	$<1.7 \times 10^{-8}$
Benzyl benzoate	25	$<1 \times 10^{-9}$
Bromine	17.2	1.3×10^{-13}
Bromobenzene	25	$<2 \times 10^{-11}$
Bromoform	25	$<2 \times 10^{-8}$
iso-Butyl alcohol	25	8×10^{-8}
Capronitrile	25	3.7×10^{-6}
Carbon disulfide	1	7.8×10^{-18}
Carbon tetrachloride	18	4×10^{-18}
Chlorine	−70	$<1 \times 10^{-16}$
Chloroacetic acid	60	1.4×10^{-6}
m-Chloroaniline	25	5×10^{-8}
Chloroform	25	$<2 \times 10^{-8}$
Chlorohydrin	25	5×10^{-7}
m-Cresol	25	$<1.7 \times 10^{-8}$
Cyanogen	···	$<7 \times 10^{-9}$
Cymene	25	$<2 \times 10^{-8}$
Dichloroacetic acid	25	7×10^{-8}
Dichlorohydrin	25	1.2×10^{-5}
Diethylamine	−33.5	2.2×10^{-9}
Diethyl carbonate	25	1.7×10^{-8}
Diethyl oxalate	25	7.6×10^{-7}
Diethyl sulfate	25	2.6×10^{-7}
Dimethyl sulfate	0	1.6×10^{-7}
Epichlorohydrin	25	3.4×10^{-8}
Ethyl acetate	25	$<1 \times 10^{-9}$
Ethyl acetoacetate	25	4×10^{-8}
Ethyl alcohol	25	1.35×10^{-9}
Ethylamine	0	4×10^{-7}
Ethyl benzoate	25	$<1 \times 10^{-9}$
Ethyl bromide	25	$<2 \times 10^{-8}$
Ethylene bromide	19	$<2 \times 10^{-10}$
Ethylene chloride	25	3×10^{-8}
Ethyl ether	25	$<4 \times 10^{-13}$
Ethylidene chloride	25	$<1.7 \times 10^{-8}$
Ethyl iodide	25	$<2 \times 10^{-8}$
Ethyl isothiocyanate	25	1.26×10^{-7}
Ethyl nitrate	25	5.3×10^{-7}
Ethyl thiocyanate	25	1.2×10^{-6}
Eugenol	25	$<1.7 \times 10^{-8}$
Formamide	25	4×10^{-6}
Formic acid	18	5.6×10^{-5}
	25	6.4×10^{-5}
Furfural	25	1.5×10^{-6}
Gallium	30	36,800
Glycerol	25	6.4×10^{-8}
Glycol	25	3×10^{-7}
Guaiacol	25	2.8×10^{-7}
Heptane	···	$<1 \times 10^{-13}$
Hexane	18	$<1 \times 10^{-18}$
Hydrogen bromide	−80	8×10^{-9}
Hydrogen chloride	−96	1×10^{-8}
Hydrogen cyanide	0	3.3×10^{-6}
Hydrogen iodide	B.P.	2×10^{-7}
Hydrogen sulfide	B.P.	1×10^{-11}
Iodine	110	1.3×10^{-10}
Kerosene	25	$<1.7 \times 10^{-8}$
Mercury	0	10,629.6
Methyl acetate	25	3.4×10^{-6}
Methyl alcohol	18	4.4×10^{-7}
Methyl ethyl ketone	25	1×10^{-7}
Methyl iodide	25	$<2 \times 10^{-8}$
Methyl nitrate	25	4.5×10^{-6}
Methyl thiocyanate	25	1.5×10^{-6}
Naphthalene	82	4×10^{-10}
Nitrobenzene	0	5×10^{-9}
Nitromethane	18	6×10^{-7}
o- or *m*-Nitrotoluene	25	$<2 \times 10^{-7}$
Nonane	25	$<1.7 \times 10^{-8}$

TABLE 8.34 Electrical Conductivity of Various Pure Liquids (*Continued*)

Liquid	Temp. °C	mhos/cm or $ohm^{-1} \cdot cm^{-1}$	Liquid	Temp. °C	mhos/cm or $ohm^{-1} \cdot cm^{-1}$
Oleic acid	15	$<2 \times 10^{-10}$	Salicylaldehyde	25	1.6×10^{-7}
			Stearic acid	80	$<4 \times 10^{-13}$
Pentane	19.5	$<2 \times 10^{-10}$	Sulfonyl chloride, $SOCl_2$	25	2×10^{-6}
Petroleum	···	3×10^{-13}	Sulfur	115	1×10^{-12}
Phenetole	25	$<1.7 \times 10^{-8}$		130	5×10^{-12}
Phenol	25	$<1.7 \times 10^{-8}$		440	1.2×10^{-7}
Phenyl isothiocyanate	25	1.4×10^{-6}	Sulfur dioxide	35	1.5×10^{-8}
Phosgene	25	7×10^{-9}	Sulfuric acid	25	1×10^{-2}
Phosphorus	25	4×10^{-7}	Sulfuryl chloride, SO_2Cl_2	25	3×10^{-8}
Phosphorus oxychloride	25	2.2×10^{-6}			
Pinene	23	$<2 \times 10^{-10}$	Toluene	···	$<1 \times 10^{-14}$
Piperidine	25	$<2 \times 10^{-7}$	*o*-Toluidine	25	$<2 \times 10^{-6}$
Propionaldehyde	25	8.5×10^{-7}	*p*-Toluidine	100	6.2×10^{-8}
Propionic acid	25	$<1 \times 10^{-9}$	Trichloroacetic acid	25	3×10^{-9}
Propionitrile	25	$<1 \times 10^{-7}$	Trimethylamine	−33.5	2.2×10^{-10}
n-Propyl alcohol	18	5×10^{-8}	Turpentine	···	2×10^{-13}
	25	2×10^{-8}			
iso-Propyl alcohol	25	3.5×10^{-6}	*iso*-Valeric acid	80	$<4 \times 10^{-13}$
n-Propyl bromide	25	$<2 \times 10^{-8}$			
Pyridine	18	5.3×10^{-8}	Water	18	4×10^{-8}
Quinoline	25	2.2×10^{-8}	Xylene	···	$<1 \times 10^{-15}$

TABLE 8.35 Equivalent Conductivities of Electrolytes in Aqueous Solutions at 18°C

The unit of Λ in the table is $\Omega^{-1} \cdot cm^{-2} \cdot equiv^{-1}$. The entities to which the equivalent relates are given in the first column.

Electrolyte	Concentration, *N*										
	0.001	0.005	0.01	0.05	0.1	0.5	1.0	2.0	3.0	4.0	5.0
Acetic acid	41	20.0	14.3	6.48	4.60	2.01	1.32		0.54		0.29
$AgNO_3$	113.2	110.0	107.8	99.5	94.3	77.8	67.8	56.0	48.2	42.1	37.2
$\frac{1}{2}Ag_2SO_4$	116.3	108.4	102.9								
$\frac{1}{3}AlBr_3$ (25°)	132	124	119	103	97						
$\frac{1}{3}AlCl_3$	121.1	105.0	93.8			65.0	56.2	44.2	34.7	27.2	
$\frac{1}{3}AlI_3$ (25°)	131	124	119	108							
$\frac{1}{3}Al(NO_3)_3$ (25°)	123	115	110	94	88						
$\frac{1}{6}Al_2(SO_4)_3$ (25°)	107.2	76.8	60.6								
$\frac{1}{2}Ba(OAc)_2$	85.0	80.4	77.1	65.7	60.2	43.8	34.3				
$\frac{1}{2}Ba(BrO_3)_2$ (25°)	113.6	106.8	102.7								
$\frac{1}{2}BaCl_2$	115.6	112.3	106.7	96.0	90.8	77.3	70.1	60.3	52.3		
$\frac{1}{2}Ba(NO_3)_2$	111.7	105.3	101.0	86.8	78.9	56.6	48.4		29.8	23.4	
$\frac{1}{2}Ba(OH)_2$	216	213	207	191	180						
Butyric acid						1.66	0.98	0.46	0.26	0.18	0.11
$\frac{1}{2}Ca(OAc)_2$	79.6	75.0	71.9	60.3	54.0	36.3	26.3				
$\frac{1}{2}CaCl_2$	112.0	106.7	103.4	93.3	88.2	74.9	67.5	58.3	49.7	42.4	35.6
$\frac{1}{2}Ca(NO_3)_2$	108.5	103.0	99.5	88.4	82.5	65.7	55.9	43.5	35.5	26.0	21.5
$\frac{1}{2}Ca(OH)_2$		233	226								
$\frac{1}{2}CaSO_4$	104.3	86.3	77.4								
$\frac{1}{2}CdBr_2$		86.5	76.3	53.2	44.6	25.3	18.3	12.5	9.1	6.8	5.3
$\frac{1}{2}CdCl_2$		91	83	59	50	30.8	22.4	14.4	9.9	7.1	5.4
$\frac{1}{2}CdI_2$		76.7	65.6	40.1	31.0	18.3	15.4	12.3	9.7	8.0	
$\frac{1}{2}Cd(NO_3)_2$		100	96	86.4	80.8	63.9	54.5	41.0	31.4	23.7	17.6
$\frac{1}{2}CdSO_4$	97.7	79.7	70.3	49.6	42.2	28.7	23.6	17.7	14.0	11.0	8.35
$\frac{1}{3}CeCl_3$ (25°)	137.4		122.1		99.0						
$\frac{1}{6}Ce_2(C_2O_4)_3$ (25°)	85.5	54	45.8	29							
Chloroacetic acid (25°)					42.9	20.2	13.6	8.1	5.6	4.2	3.3
Citric acid	88.4	54	42.5	22.0	16.1	7.3	5.4				
$\frac{1}{2}CoCl_2$		99.3	95.6	82.3	75.0	51.5	45.3	40.3	35.4	30.5	26.4
$\frac{1}{3}CrCl_3$						68.6	56.8	44.8	35.2		

TABLE 8.35 Equivalent Conductivities of Electrolytes in Aqueous Solutions at 18°C (*Continued*)

Electrolyte	Concentration, *N*										
	0.001	0.005	0.01	0.05	0.1	0.5	1.0	2.0	3.0	4.0	5.0
½CrO_3(H_2CrO_4) (25°)	201	195	193	191	186						
CsCl	130.7	127.5	125.2		113.5	104.3	100.3	95.7	85.1		
½$Cu(OAc)_2$ (25°)	55.7	50.6	47.2	34.9	28.4						
½$CuCl_2$								41.2	31.5	24.5	19.1
½$Cu(NO_3)_2$ (15°)	107.9	97.1	93.7	83.7	78.2	67.5	56.8	45.4	35.3	27.8	21.4
½$CuSO_4$	98.5	81.0	71.7	53.6	43.8	30.5	25.6	19.7	16.5		
Dichloroacetic acid (25°)					207.5	119	82	44.6	26.5	16.3	9.6
½$FeCl_2$ (25°)	131	125	120	103	93						
⅓$FeCl_3$						66.5	52.9	37.6	28.1	20.5	15.9
½$FeSO_4$	82	75	70	54	44.5	30.8	25.8	19.5	15.37		
Formic acid	125.6						5.18	3.68	2.93	2.39	1.92
H_3AsO_4 (1 *M*) (25°)	308.2	230.0	187.0	103.4	80.4						
H_3BO_3	13.5										
HBr					356	306	282	243	214	179	
$HBrO_3$ (25°)	401	387	373	272	156						
HCl	377	373	370	360	351	327	301		215		152.2
$HClO_3$					343	317	292	247	207		
$HClO_4$ (25°)	413	406	402	392	386	358					
HF		90	60	35.9	31.3	27.0	25.7		24.2		24.0
HI					347	322	297	255	215	179	
HIO_3	343.3	332.8	323.9		253	175	141	106	87	71	
HNO_3	375	371	368	357	350	324	310		220		156
H_3PO_4 (1 *M*)	318	279	255				66		53.1		51.3
HSCN (25°)	399	394	390	377	370						
½H_2SO_4	361	330	308	253	225	205	198		166.8		135.0
½$HgCl_2$				1.85	1.23						
⅓$InBr_3$					53.9	37.0	28.7	19.8	14.4	10.1	
KOAc	98.3	95.7	94.0	87.7	83.8	71.6	63.4	50.0	40.7	31.4	24.5
KBr	129.4	126.4	124.4	117.8	114.2	105.4	102.5	98.0	93.3	87.9	
$KBrO_3$	109.9	106.9	104.7	97.3	93.0						
⅓K_3citrate		109.9	103	87.8	80.8						

KCl	127.3	124.4	122.4	115.8	112.0	102.4	98.3	92.0	88.9		
$KClO_3$	116.9	113.6	111.6	103.7	99.2	85.3					
$KClO_4$ (25°)	137.9	134.2	131.5	121.6	115.2						
KCN (15°)						104.2	99.7				
$½K_2CO_3$	133.0	121.6	115.5	100.7	94.1	77.8	70.7	65.0	55.6	49.2	42.9
$½K_2C_2O_4$	122.4	116.7	112.5	100.8	94.9	80.4	73.7				
$½K_2CrO_4$					100.5	86.4	79.5	72.0	59.9		
$½K_2Cr_2O_7$					98.2	85.4					
KF	108.9	106.2	104.3	97.7	94.0	82.6	76.0	63.4	56.5	51.7	46.5
$⅓K_3[Fe(CN)_6]$	163.1	150.7									
$¼K_4[Fe(CN)_6]$	167.2	146.1	134.8	107.7	97.9						
$KHCO_3$ (25°)	115.3	112.2	110.1			86.5	78.9				
KH phthalate	119.3	103.7	99.9	89.3	83.8						
KHS						92.5	91.7	86.4	80.7		69.3
$KHSO_4$						21.0	18.4	15.2			
KH_2PO_4 (1 *M*) (25°)	107.1	100.8	98.0	90.7	85.6	60.0[18]	45.8[18]				
KI	128.2	125.3	123.4	117.3	114.0	106.2	103.6	101.3	96.4	89.0	81.2
KIO_3	96.0	93.2	91.2	84.1	79.7						
KIO_4 (25°)	124.9	121.2	118.5	106.7	98.1						
$KMnO_4$ (25°)	133.3		126.5		113						
KNO_3	123.6	120.5	118.2	109.9	104.8	89.2	80.5	69.4	61.3		
KOH	234	230	228	219	213	197	184		140.6		105.8
$KReO_4$ (25°)	125.1	121.3	118.5	106.4	97.4						
$½K_2S$							135.6	119.7	108.3	97.2	86.1
KSCN	118.6	115.8	113.9	107.7	104.3	95.7	91.6	86.8	74.6		
$½K_2SO_4$	126.9	120.3	115.8	101.9	94.9	78.5	71.6				
$½LaCl_3$ (25°)	137.0	127.5	121.8	106.2	99.1						
$⅓La(NO_3)_3$				86.1	72.1	65.4	54.0	39.1	28.5	19.9	
$⅙La_2(SO_4)_3$				25.7	21.5						
Lactic acid	108.9	53.5	39	18.1	13.2						
LiOAc					51.3	37.7	28.9	18.2	11.9	7.2	
LiBr				87.9	84.4	73.9	67.2	57.7		44.2	
LiCl	96.5	93.9	92.1	86.1	82.4	70.7	63.4	53.1	45.3		33.3
$LiClO_4$ (25°)	103.4	100.6	98.6	92.2	88.6						
$½Li_2CO_3$				64.2	59.1						
LiI						75.3	69.2	61.0			
$LiIO_3$	65.3	62.9	61.2	55.3	51.5	39.0	31.2	21.4	14.6		

TABLE 8.35 Equivalent Conductivities of Electrolytes in Aqueous Solutions at 18°C (*Continued*)

Electrolyte	Concentration, *N*										
	0.001	0.005	0.01	0.05	0.1	0.5	1.0	2.0	3.0	4.0	5.0
$LiNO_3$	92.9	90.3	88.6	82.7	79.2	68.0	60.8	50.3	34.9	27.3	
LiOH						149.0	134.5	113.5	95.7		
$½Li_2SO_4$	96.4		86.9	74.7	68.2	50.5	41.3	30.7	23.3	18.1	13.9
$½MgCl_2$	106.4	101.3	98.1	88.5	83.4	69.6	61.5	52.3	43.3	35.0	28.0
$½Mg(NO_3)_2$	102.6	97.7	94.7	85.3	80.5	67.0	59.0	47.0	39.8		
$½MgSO_4$	99.8	84.5	76.2	56.9	49.7	35.4	28.9	23.0	17.3	12.9	9.3
$½MnCl_2$					86.0	68.5	61.0	48.5	38.8	30.2	23.0
$½MnSO_4$						27.6	24.4	18.3	14.0	10.5	7.3
NH_3(aq)	28.0	13.2	9.6	4.6	3.3	1.35	0.89		0.36		0.20
NH_4OAc		92.9	91.4	84.9		60.5	54.7	42.9	34.0	26.5	
NH_4Cl	127.3	124.3	122.1	115.2	110.7	101.4	97.0	92.1	88.2	85.0	80.7
NH_4F					90.1	74.5	65.7	55.3	47.9	42.2	
NH_4I				118.0	115.0	106.0	103.1	100.0		91.4	84.5
NH_4NO_3	124.5		118.0	110.0	106.6	94.5	88.8	85.1		71.9	47.6
NH_4SCN					104.3	94.0	89.9	84.7	79.2	74.0	
$½(NH_4)_2SO_4$		120.0	116.5		89.0	79.5	73.0	65.0		55.2	
NaOAc	75.2	72.4	70.2	64.2	61.1	49.4	41.2	29.8	21.5	15.3	10.5
NaBr				99.1	96.0	84.6	78.1	69.1		53.0	
$NaBrO_3$						61.8	54.5	44.1			
Na *n*-butyrate (25°)	80.3	77.6	75.8	69.3	65.3						
NaCl	106.5	103.8	102.0	95.7	92.0	80.9	74.3	64.8	56.5	49.4	42.7
$NaClO_4$	114.9[25]	111.7[25]	109.6[25]	102.4[25]	98.4[25]	71.7	65.0	55.1	46.0	38.8	
$½Na_2CO_3$	112	102.5	96.2	80.3	72.9	54.5	45.5	34.5	27.2		
$½Na_2CrO_4$					82.5	66.4	57.7	46.6	38.3	31.1	
$½Na_2Cr_2O_7$ (25°)		103		98.3	94.9						
NaF	87.8	85.2	83.5	77.0	73.1	60.0	51.9				
$¼Na_4[Fe(CN)_6]$ (25°)		129.6	120.0	97.0	88.2						
Na formate	88.6					61.4	53.7	43.1	34.8	28.2	
$NaHCO_3$ (25°)	93.5	90.5	88.4	80.6	76.0						
$⅓Na_2HPO_4$	58.4		54.0		44.0	33.5	28.0				
NaH_2PO_4	67.9	65.8	64.4	57.8	54.1						
$¼Na_2H_2P_2O_7$	41.1	39.4	38.2	34.6	32.5	25.4					
NaI	124.2	121.2	119.2	112.8	108.8	97.5	89.9	78.6	69.9	62.2	

$NaIO_3$	75.2	72.6	70.9	64.4	60.5						
$½Na_2MoO_4$	120.8	113	110								
NaN_3 (25°)	117.1	113.8	110.5	101.3	95.7		68.0				
$NaNO_2$ (25°)							75.9	63.1	53.6		39.7
$NaNO_3$	102.9	100.1	98.2	91.4	87.2	74.1	65.9	54.5	46.0	39.0	
NaOH	208	203	200	190	183	172	160		108.0		69.0
Na picrate (25°)	78.6	75.7	73.7	66.3	61.8						
$⅓Na_3PO_4$	125	122	119	91							
Na propionate (25°)	83.5	80.9	79.1								
$½Na_2S$						117.0	104.3	85.0	71.0	59.0	47.2
NaSCN						74.3	68.9	59.8	50.9	43.7	
$½Na_2SiO_3$	144	139	136	124	116	88	72	51	38	27	19
$½Na_2SO_4$	106.7	100.8	96.8	83.9	78.4	59.7	50.8	40.0	33.5		
(mono) Na tartrate	120	81.5	74.8	64.3	60.4						
$½Na_2WO_4$ (25°)	116.1	109.2	104.8	92.2	85.8						
$½NiSO_4$	96.3	79.5	70.8	51.0	43.8	30.4	25.1	19.3	15.1		
½Oxalic acid	180.7		158.2	132.9	116.9	75.9	59.4				
$½Pb(NO_3)_2$	116.1	108.6	103.5	86.3	77.3	53.2	42.0	31.0			
Propionic acid						1.57	1.00	0.54		0.20	
RbCl	130.3	127.4	125.3	117.8	113.9		101.9	97.1	92.7	87.2	
RbOH					220.6	204.8	192.0	170.0	148.3		
$¼SnCl_4$						216.8	121.7	66.9	47.9	32.7	
$½SrCl_2$	114.5	108.9	105.4	94.4	90.2	75.7	68.5	58.7	49.9	42.2	
$½Sr(NO_3)_2$	108.3	102.7	99.0	87.3	80.9	62.7	52.1	38.0	29.3	29.3	16.4
Tartaric acid (15°)							7.03	4.58	3.32	2.48	1.83
$¼ThCl_4$						61.0	54.0	44.3	36.3	29.8	
TlCl	128.2	123.7	120.2								
TlF	113.3	108.2	105.4	97.4	92.6	78.8	71.5	62.7			
$TlNO_3$	124.7	121.1	118.4	107.9	101.2						
$½Tl_2SO_4$	127.4	118.4	112.3	92.7	83.1						
Trichloroacetic acid (25°)						273	207	127	79	44	19
$½UO_2F_2$ (25°)	26.10	12.31	9.17	5.43	4.74	3.75	3.22				
$½UO_2SO_4$ (25°)	106.5	63.2	49.2	27.6	22.2	14.4	11.6				2.7
$⅓YCl_3$ (25°)	129	122	118	109							
$½Zn(OAc)_2$ (25°)	83	77	73	58	49						
$½ZnCl_2$	107	101	98	87	82	65	55	39.6	29.6	23.2	18.5
$½Zn(NO_3)_2$	120	114	111	100							
$½ZnSO_4$	98.4	82.1	73.2	53.0	45.6	32.3	26.6	20.0	15.9	12.0	9.0

TABLE 8.36 Conductivity of Very Pure Water at Various Temperatures and the Equivalent Conductances of Hydrogen and Hydroxyl Ions

			Equivalent conductance, $cm^2 \cdot ohm^{-1} \cdot equivalent^{-1}$	
Temp., °C	Conductivity, $\mu S \cdot cm^{-1}$	Resistivity, $M\Omega \cdot cm$	λ^0, H^+	λ^0, OH^-
0	0.011 61	86.14	224.1	117.8
5	0.016 61	60.21	250.0	133.6
10	0.023 15	43.21	275.6	149.6
15	0.031 53	31.71	300.9	165.9
18	0.037 54	26.64	315.8	491.6
20	0.042 05	23.78	325.7	182.5
25	0.055 08	18.15	350.1	199.2
30	0.070 96	14.09	374.0	216.1
35	0.090 05	11.10	397.4	233.0
40	0.112 7	8.88	420.0	267.2
45	0.139 3	7.18	442.0	267.2
50	0.170 2	5.88	463.3	284.3
55	0.205 5	4.86	483.8	301.4
60	0.245 7	4.06	503.4	318.5
65	0.291 2	3.43	522.0	335.4
70	0.341 6	2.93	539.7	352.2
75	0.397 8	2.51	556.4	368.8
80	0.459 3	2.18	572.0	385.2
85	0.525 8	1.90	586.4	401.4
90	0.597 7	1.67	599.6	417.3
95	0.675 3	1.48	611.6	432.8
100	0.756 9	1.32	622.2	448.1
150	1.84	0.543		
200	2.99	0.334	824	701
250	3.31	0.302		
300	2.42	0.413	894	821

Source: Data from T. S. Light and S. L. Licht, *Anal. Chem.*, **59:**2327–2330 (1987).

8.7.1 Common Conductance Relations*

Conductivity. The standard unit of conductance is electrolytic conductivity (formerly called specific conductance) κ, which is defined as the reciprocal of the resistance [Ω^{-1}] of a 1-m cube of liquid at a specified temperature [$\Omega^{-1} \cdot m-1$]. See Table 8.33 and the definition of the cell constant.

In accurate work at low concentrations it is necessary to subtract the conductivity of the pure solvent (Table 8.34) from that of the solution to obtain the conductivity due to the electrolyte.

Resistivity (Specific Resistance)

$$\rho = \frac{1}{\kappa} \qquad [\Omega \cdot m]$$

* SI units are in brackets.

Conductance of an Electrolyte Solution

$$\frac{1}{R} = \kappa \frac{S}{d} \qquad [\Omega^{-1}]$$

where S is the surface area of the electrode, or the mean cross-sectional area of the solution [m^2], and d is the mean distance between the electrodes [m].

Equivalent Conductivity

$$\Lambda = \frac{\kappa}{C} \qquad [\Omega^{-1} \cdot m^2 \cdot \text{equiv}^{-1}]$$

In the older literature, C is the concentration in equivalents per liter. The volume of the solution in cubic centimeters per equivalent is equal to $1000/C$, and $\Lambda = 1000\ \kappa/C$, the units employed in Table 8.32 [$\Omega^{-1} \cdot cm^2 \cdot \text{equiv}^{-1}$]. The formula unit used in expressing the concentration must be specified; for example, NaCl, $\frac{1}{2}K_2SO_4$, $\frac{1}{3}LaCl_3$.

The equivalent conductivity of an electrolyte is the sum of contributions of the individual ions. At infinite dilution: $\Lambda^\circ = \lambda_c^\circ + \lambda_a^\circ$, where λ_c° and λ_a° are the ionic conductances of cations and anions, respectively, at infinite dilution (Table 8.35).

Ionic Mobility and Ionic Equivalent Conductivity

$$\lambda_c = Fu_c \qquad \text{and} \qquad \lambda_a = Fu_a \qquad [\Omega^{-1} \cdot m^2 \cdot \text{equiv}^{-1}]$$

where F is the Faraday constant, and u_c, u_a are the ionic mobilities [$m^2 \cdot s^{-1} \cdot V^{-1}$].

$$\Lambda = \alpha F(u_c + u_a) = \alpha(\lambda_c + \lambda_a)$$

where α is the degree of electrolytic dissociation, Λ/Λ°. The electric mobility u of a species is the magnitude of the velocity in an electric field [$m \cdot s^{-1}$] divided by the magnitude of the strength of the electric field E[$V \cdot m^{-1}$].

Ostwald Dilution Law

$$K_d = \frac{\alpha^2 C}{1 - \alpha}$$

where K_d is the dissociation constant of the weak electrolyte. In general for an electrolyte which yields n ions:

$$K_d = \frac{C^{(n-1)}\Lambda^n}{\Lambda^{\circ(n-1)}(\Lambda^\circ - \Lambda)}$$

Transference Numbers or Hittorf Transport Numbers

$$T_c = \frac{\lambda_c}{\lambda_c + \lambda_a} \qquad T_a = \frac{\lambda_a}{\lambda_c + \lambda_a} \qquad T_c + T_a = 1$$

$$\frac{T_c}{T_a} = \frac{u_c}{u_a} = \frac{\lambda_c}{\lambda_a}$$

$$\lambda_c = T_c\Lambda \qquad \lambda_a = T_a\Lambda$$