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# SECTION 8

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# ELECTROLYTES, ELECTROMOTIVE FORCE, AND CHEMICAL EQUILIBRIUM

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## 8.1 ACTIVITY COEFFICIENTS

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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:

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

where  $I$  is the ionic strength of the medium, and  $\hat{a}$  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 ( $\hat{a}$  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  $\hat{a}$  taken to be 4.6Å.

In general, the mean ionic activity coefficient is given by

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

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

Effective Ionic Radii $\bar{a}$ (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.,  $\text{BaCl}_2$  or  $\text{K}_2\text{SO}_4$ ,

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

In quaternary electrolytes, e.g.,  $\text{LaCl}_3$  or  $\text{K}_3[\text{Fe}(\text{CN})_6]$ ,

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

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

$\bar{a}$ (in Å)	Inorganic Ions	$\bar{a}$ (in Å)	Organic Ions
2.5.....	Rb <sup>+</sup> , Cs <sup>+</sup> , NH <sub>4</sub> <sup>+</sup> , Tl <sup>+</sup> , Ag <sup>+</sup>	3.5.....	HCOO <sup>-</sup> , H <sub>2</sub> Cit <sup>-</sup> , CH <sub>3</sub> NH <sub>3</sub> <sup>+</sup> , (CH <sub>3</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup>
3.....	K <sup>+</sup> , Cl <sup>-</sup> , Br <sup>-</sup> , I <sup>-</sup> , CN <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup>	4.....	H <sub>3</sub> N <sup>+</sup> CH <sub>2</sub> COOH, (CH <sub>3</sub> ) <sub>3</sub> NH <sup>+</sup> , C <sub>2</sub> H <sub>5</sub> NH <sub>3</sub> <sup>+</sup>
3.5.....	OH <sup>-</sup> , F <sup>-</sup> , SCN <sup>-</sup> , OCN <sup>-</sup> , HS <sup>-</sup> , ClO <sub>3</sub> <sup>-</sup> , ClO <sub>4</sub> <sup>-</sup> , BrO <sub>3</sub> <sup>-</sup> , IO <sub>4</sub> <sup>-</sup> , MnO <sub>4</sub> <sup>-</sup>	4.5.....	CH <sub>3</sub> COO <sup>-</sup> , ClCH <sub>2</sub> COO <sup>-</sup> , (CH <sub>3</sub> ) <sub>4</sub> N <sup>+</sup> , (C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup> , H <sub>2</sub> NCH <sub>2</sub> COO <sup>-</sup> , oxalate <sup>2-</sup> , HCit <sup>2-</sup>
4.....	Na <sup>+</sup> , CdCl <sup>+</sup> , Hg <sub>2</sub> <sup>2+</sup> , ClO <sub>2</sub> <sup>-</sup> , IO <sub>3</sub> <sup>-</sup> , HCO <sub>3</sub> <sup>-</sup> , H <sub>2</sub> PQ <sup>-</sup> , HSQ <sup>-</sup> , H <sub>2</sub> AsO <sub>4</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>3</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> , SeO <sub>4</sub> <sup>2-</sup> , CrO <sub>4</sub> <sup>2-</sup> , HPO <sub>4</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>6</sub> <sup>2-</sup> , PO <sub>4</sub> <sup>3-</sup> , Fe(CN) <sub>6</sub> <sup>3-</sup> , Cr(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup> , Co(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup> , Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O <sup>3+</sup>	5.....	Cl <sub>2</sub> CHCOO <sup>-</sup> , Cl <sub>3</sub> COO <sup>-</sup> , (C <sub>2</sub> H <sub>5</sub> ) <sub>3</sub> NH <sup>+</sup> , C <sub>3</sub> H <sub>7</sub> NH <sub>3</sub> <sup>+</sup> , Cit <sup>3-</sup> , succi- nate <sup>2-</sup> , malonate <sup>2-</sup> , tartrate <sup>2-</sup>
4.5.....	Pb <sup>2+</sup> , CO <sub>3</sub> <sup>2-</sup> , SO <sub>3</sub> <sup>2-</sup> , MoO <sub>4</sub> <sup>2-</sup> , Co(NH <sub>3</sub> ) <sub>5</sub> Cl <sup>2+</sup> , Fe(CN) <sub>5</sub> NO <sup>2-</sup>	6.....	benzoate <sup>-</sup> , hydroxybenzoate <sup>-</sup> , chlorobenzoate <sup>-</sup> , phenylace- tate <sup>-</sup> , vinylacetate <sup>-</sup> , (CH <sub>3</sub> ) <sub>2</sub> C=CHCOO <sup>-</sup> , (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> N <sup>+</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>2</sub> NH <sub>2</sub> , phthalate <sup>2-</sup> , glutarate <sup>2-</sup> , adipate <sup>2-</sup>
5.....	Sr <sup>2+</sup> , Ba <sup>2+</sup> , Ra <sup>2+</sup> , Cd <sup>2+</sup> , Hg <sup>2+</sup> , S <sup>2-</sup> , S <sub>2</sub> O <sub>4</sub> <sup>2-</sup> , WO <sub>4</sub> <sup>2-</sup> , Fe(CN) <sub>6</sub> <sup>4-</sup>	7.....	trinitrophenolate <sup>-</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>3</sub> NH <sup>+</sup> , methoxybenzoate <sup>-</sup> , pime- late <sup>2-</sup> , suberate <sup>2-</sup> , Congo red anion <sup>2-</sup>
6.....	Li <sup>+</sup> , Ca <sup>2+</sup> , Cu <sup>2+</sup> , Zn <sup>2+</sup> , Sn <sup>2+</sup> , Mn <sup>2+</sup> , Fe <sup>2+</sup> , Ni <sup>2+</sup> , Co <sup>2+</sup> , Co(en) <sub>3</sub> <sup>3+</sup> , Co(S <sub>2</sub> O <sub>3</sub> )(CN) <sub>5</sub> <sup>4-</sup>	8.....	(C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> CHCOO <sup>-</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>4</sub> N <sup>+</sup>
8.....	Mg <sup>2+</sup> , Be <sup>2+</sup>		
9.....	H <sup>+</sup> , Al <sup>3+</sup> , Fe <sup>3+</sup> , Cr <sup>3+</sup> , Sc <sup>3+</sup> , Y <sup>3+</sup> , La <sup>3+</sup> , In <sup>3+</sup> , Ce <sup>3+</sup> , Pr <sup>3+</sup> , Nd <sup>3+</sup> , Sm <sup>3+</sup> , Co(SO <sub>3</sub> ) <sub>2</sub> (CN) <sub>5</sub> <sup>5-</sup>		
11.....	Th <sup>4+</sup> , Zr <sup>4+</sup> , Ce <sup>4+</sup> , Sn <sup>4+</sup>		

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

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

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  $\dot{a}$  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 <sub>s</sub>	0.0978	0.0265	0.00535
0.7	0.0496	0.892	0.633	0.358	0.161	0.0575 <sub>s</sub>	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  $pK_w$  on a molal scale, where  $K_w$  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	$pK_w$	Temp., °C	$pK_w$	Temp., °C	$pK_w$
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) <sub>3</sub>	15	$1 \times 10^{-15}$
Aluminum arsonate	AlAsO <sub>4</sub>	15.80	$1.6 \times 10^{-16}$
cupferrate	AlL <sub>3</sub>	18.64	$2.3 \times 10^{-19}$
hydroxide	Al(OH) <sub>3</sub>	32.89	$1.3 \times 10^{-33}$
phosphate	AlPO <sub>4</sub>	20.01	$9.84 \times 10^{-21}$
8-quinolinolate	AlL <sub>3</sub>	29.00	$1.00 \times 10^{-29}$
selenide	Al <sub>2</sub> Se <sub>3</sub>	24.4	$4 \times 10^{-25}$
sulfide	Al <sub>2</sub> S <sub>3</sub>	6.7	$2 \times 10^{-7}$
Americium (III) hydroxide	Am(OH) <sub>3</sub>	19.57	$2.7 \times 10^{-20}$
(IV) hydroxide	Am(OH) <sub>4</sub>	56	$1 \times 10^{-56}$
Ammonium uranyl arsenate	NH <sub>4</sub> UO <sub>2</sub> AsO <sub>4</sub>	23.77	$1.7 \times 10^{-24}$
Arsenic (III) sulfide	As <sub>2</sub> S <sub>3</sub>	21.68	$2.1 \times 10^{-22}$

TABLE 8.6 Solubility Product Constants (Continued)

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

TABLE 8.6 Solubility Product Constants (Continued)

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



TABLE 8.6 Solubility Product Constants (Continued)

Compound	Formula	$pK_{sp}$	$K_{sp}$
perchlorate	CsClO <sub>4</sub>	2.40	$3.95 \times 10^{-3}$
periodate	CsIO <sub>4</sub>	5.29	$5.16 \times 10^{-6}$
permanganate	CsMnO <sub>4</sub>	4.08	$8.2 \times 10^{-5}$
perrhanate	CsReO <sub>4</sub>	3.40	$4.0 \times 10^{-4}$
tetrafluoroborate	Cs[BF <sub>4</sub> ]	4.7	$5 \times 10^{-5}$
Chromium(II)			
hydroxide	Cr(OH) <sub>2</sub>	15.7	$2 \times 10^{-16}$
Chromium(III)			
arsenate	CrAsO <sub>4</sub>	20.11	$7.7 \times 10^{-21}$
fluoride	CrF <sub>3</sub>	10.18	$6.6 \times 10^{-11}$
hydroxide	Cr(OH) <sub>3</sub>	30.20	$6.3 \times 10^{-31}$
phosphate 4-water	CrPO <sub>4</sub> ·4H <sub>2</sub> O green	22.62	$2.4 \times 10^{-23}$
	violet	17.00	$1.0 \times 10^{-17}$
Cobalt			
anthranilate	CoL <sub>2</sub>	9.68	$2.1 \times 10^{-10}$
arsenate	Co <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub>	28.17	$6.80 \times 10^{-29}$
carbonate	CoCO <sub>3</sub>	12.84	$1.4 \times 10^{-13}$
ferrocyanide	Co <sub>2</sub> [Fe(CN) <sub>6</sub> ]	14.74	$1.8 \times 10^{-15}$
hydrogen phosphate	CoHPO <sub>4</sub>	6.7	$2 \times 10^{-7}$
(II) hydroxide	Co(OH) <sub>2</sub> fresh	14.23	$5.92 \times 10^{-15}$
(III) hydroxide	Co(OH) <sub>3</sub>	43.80	$1.6 \times 10^{-44}$
iodate	Co(IO <sub>3</sub> ) <sub>2</sub>	4.0	$1.0 \times 10^{-4}$
phosphate	Co <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	34.69	$2.05 \times 10^{-35}$
selenite	CoSeO <sub>3</sub>	6.80	$1.6 \times 10^{-7}$
quinaldate	CoL <sub>2</sub>	10.80	$1.6 \times 10^{-11}$
8-quinolinolate	CoL <sub>2</sub>	24.80	$1.6 \times 10^{-25}$
sulfide	$\alpha$ -CoS	20.40	$4.0 \times 10^{-21}$
	$\beta$ -CoS	24.70	$2.0 \times 10^{-25}$
Copper(I)			
azide	CuN <sub>3</sub>	8.31	$4.9 \times 10^{-9}$
bromide	CuBr	8.20	$6.27 \times 10^{-9}$
chloride	CuCl	6.76	$1.72 \times 10^{-7}$
cyanide	CuCN	19.46	$3.47 \times 10^{-20}$
hydroxide	CuOH	14	$1 \times 10^{-14}$
iodide	CuI	11.90	$1.27 \times 10^{-12}$
sulfide	Cu <sub>2</sub> S	47.60	$2.5 \times 10^{-48}$
tetraphenylborate	CuL	8.0	$1.0 \times 10^{-8}$
thiocyanate	CuSCN	12.75	$1.77 \times 10^{-13}$
Copper(II)			
anthranilate	CuL <sub>2</sub>	13.22	$6.0 \times 10^{-14}$
arsenate	Cu <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub>	35.10	$7.95 \times 10^{-36}$
azide	Cu(N <sub>3</sub> ) <sub>2</sub>	9.20	$6.3 \times 10^{-10}$
carbonate	CuCO <sub>3</sub>	9.86	$1.4 \times 10^{-10}$
chromate	CuCrO <sub>4</sub>	5.44	$3.6 \times 10^{-6}$
dithiooxamide	CuL	15.12	$7.67 \times 10^{-16}$
ferrocyanide	Cu <sub>2</sub> [Fe(CN) <sub>6</sub> ]	15.89	$1.3 \times 10^{-16}$
hydroxide	Cu(OH) <sub>2</sub>	19.66	$2.2 \times 10^{-20}$
iodate	Cu(IO <sub>3</sub> ) <sub>2</sub>	7.16	$6.94 \times 10^{-8}$
oxalate	CuC <sub>2</sub> O <sub>4</sub>	9.35	$4.43 \times 10^{-10}$
phosphate	Cu <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	36.85	$1.40 \times 10^{-37}$
pyrophosphate	Cu <sub>3</sub> P <sub>2</sub> O <sub>7</sub>	15.08	$8.3 \times 10^{-16}$
quinaldate	CuL <sub>2</sub>	16.80	$1.6 \times 10^{-17}$
8-quinolinolate	CuL <sub>2</sub>	29.70	$2.0 \times 10^{-30}$

**TABLE 8.6** Solubility Product Constants (*Continued*)

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

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	$pK_{sp}$	$K_{sp}$
hydroxide	$\text{La}(\text{OH})_3$	18.70	$2.0 \times 10^{-19}$
iodate	$\text{La}(\text{IO}_3)_3$	11.12	$7.50 \times 10^{-12}$
molybdate	$\text{La}_2(\text{MoO}_4)_3$	20.4	$4 \times 10^{-21}$
oxalate 9-water	$\text{La}_2(\text{C}_2\text{O}_4)_3$	26.60	$2.5 \times 10^{-27}$
phosphate	$\text{LaPO}_4$	22.43	$3.7 \times 10^{-23}$
sulfide	$\text{La}_2\text{S}_3$	12.70	$2.0 \times 10^{-13}$
tungstate trihydrate	$\text{La}_2(\text{WO}_4)_3 \cdot 3\text{H}_2\text{O}$	3.90	$1.3 \times 10^{-4}$
Lead			
acetate	$\text{Pb}(\text{OAc})_2$	2.75	$1.8 \times 10^{-3}$
anthranilate	$\text{PbL}_2$	9.81	$1.6 \times 10^{-10}$
arsenate	$\text{Pb}_3(\text{AsO}_4)_3$	35.39	$4.0 \times 10^{-36}$
azide	$\text{Pb}(\text{N}_3)_2$	8.59	$2.5 \times 10^{-9}$
borate, <i>meta</i>	$\text{Pb}(\text{BO}_2)_3$	10.78	$1.6 \times 10^{-11}$
bromate	$\text{Pb}(\text{BrO}_3)_2$	1.70	$2.0 \times 10^{-2}$
bromide	$\text{PbBr}_2$	6.82	$6.60 \times 10^{-6}$
carbonate	$\text{PbCO}_3$	13.13	$7.4 \times 10^{-14}$
chloride	$\text{PbCl}_2$	4.77	$1.70 \times 10^{-5}$
chloride fluoride	$\text{PbClF}$	8.62	$2.4 \times 10^{-9}$
chlorite	$\text{Pb}(\text{ClO}_2)_2$	8.4	$4 \times 10^{-9}$
chromate	$\text{PbCrO}_4$	12.55	$2.8 \times 10^{-13}$
ferrocyanide	$\text{Pb}_2[\text{Fe}(\text{CN})_6]$	14.46	$3.5 \times 10^{-15}$
fluoride	$\text{PbF}_2$	7.48	$3.3 \times 10^{-8}$
fluoride iodide	$\text{PbFI}$	8.07	$8.5 \times 10^{-9}$
hydrogen phosphate	$\text{PbHPO}_4$	9.90	$1.3 \times 10^{-10}$
hydrogen phosphite	$\text{PbHPO}_3$	6.24	$5.8 \times 10^{-7}$
hydroxide	$\text{Pb}(\text{OH})_2$	14.84	$1.43 \times 10^{-15}$
hydroxide bromide	$\text{PbOHBr}$	14.70	$2.0 \times 10^{-15}$
hydroxide chloride	$\text{PbOHCl}$	13.7	$2 \times 10^{-14}$
hydroxide nitrate	$\text{PbOHNO}_3$	3.55	$2.8 \times 10^{-4}$
iodate	$\text{Pb}(\text{IO}_3)_2$	12.43	$3.69 \times 10^{-13}$
iodide	$\text{PbI}_2$	8.01	$9.8 \times 10^{-9}$
molybdate	$\text{PbMoO}_4$	13.00	$1.0 \times 10^{-13}$
niobate	$\text{Pb}(\text{NbO}_3)_2$	16.62	$2.4 \times 10^{-17}$
oxalate	$\text{PbC}_2\text{O}_4$	9.32	$4.8 \times 10^{-10}$
phosphate	$\text{Pb}_3(\text{PO}_4)_2$	42.10	$8.0 \times 10^{-43}$
quinaldate	$\text{PbL}_2$	10.60	$2.5 \times 10^{-11}$
selenate	$\text{PbSeO}_4$	6.84	$1.37 \times 10^{-7}$
selenite	$\text{PbSeO}_3$	11.50	$3.2 \times 10^{-12}$
sulfate	$\text{PbSO}_4$	7.60	$2.53 \times 10^{-8}$
sulfide	$\text{PbS}$	27.10	$8.0 \times 10^{-28}$
thiocyanate	$\text{Pb}(\text{SCN})_2$	4.70	$2.0 \times 10^{-5}$
thiosulfate	$\text{PbS}_2\text{O}_3$	6.40	$4.0 \times 10^{-7}$
tungstate	$\text{PbWO}_4$	6.35	$4.5 \times 10^{-7}$
Lead(IV)			
hydroxide	$\text{Pb}(\text{OH})_4$	65.50	$3.2 \times 10^{-66}$
Lithium			
carbonate	$\text{Li}_2\text{CO}_3$	1.60	$2.5 \times 10^{-2}$
fluoride	$\text{LiF}$	2.74	$1.84 \times 10^{-3}$
phosphate	$\text{Li}_3\text{PO}_4$	10.63	$2.37 \times 10^{-11}$
uranylarsenate	$\text{LiUO}_2\text{AsO}_4$	18.82	$1.5 \times 10^{-19}$
Lutetium			
hydroxide	$\text{Lu}(\text{OH})_3$	23.72	$1.9 \times 10^{-24}$

TABLE 8.6 Solubility Product Constants (Continued)

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

TABLE 8.6 Solubility Product Constants (*Continued*)

Compound	Formula	$pK_{sp}$	$K_{sp}$
quinaldate	HgL <sub>2</sub>	16.80	$1.6 \times 10^{-17}$
selenite	HgSeO <sub>3</sub>	13.82	$1.5 \times 10^{-14}$
sulfide	HgS red	52.4	$4 \times 10^{-53}$
	HgS black	51.80	$1.6 \times 10^{-52}$
Neodymium			
carbonate	Nd <sub>2</sub> (CO <sub>3</sub> ) <sub>3</sub>	32.97	$1.08 \times 10^{-33}$
hydroxide	Nd(OH) <sub>3</sub>	21.49	$3.2 \times 10^{-22}$
Neptunyl(VI)			
hydroxide	NpO <sub>2</sub> (OH) <sub>2</sub>	21.60	$2.5 \times 10^{-22}$
Nickel			
ammine perrhenate	[Ni(NH <sub>3</sub> ) <sub>6</sub> ][ReO <sub>4</sub> ] <sub>2</sub>	3.29	$5.1 \times 10^{-4}$
anthranilate	NiL <sub>2</sub>	9.09	$8.1 \times 10^{-10}$
arsenate	Ni <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub>	25.51	$3.1 \times 10^{-26}$
carbonate	NiCO <sub>3</sub>	6.85	$1.42 \times 10^{-7}$
ferrocyanide	Ni <sub>2</sub> [Fe(CN) <sub>6</sub> ]	14.89	$1.3 \times 10^{-15}$
hydrazine sulfate	[Ni(N <sub>2</sub> H <sub>4</sub> ) <sub>3</sub> ]SO <sub>4</sub>	13.15	$7.1 \times 10^{-15}$
hydroxide	Ni(OH) <sub>2</sub> fresh	15.26	$5.48 \times 10^{-16}$
iodate	Ni(IO <sub>3</sub> ) <sub>2</sub>	4.33	$4.71 \times 10^{-5}$
oxalate	NiC <sub>2</sub> O <sub>4</sub>	9.4	$4 \times 10^{-10}$
phosphate	Ni <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	31.32	$4.74 \times 10^{-32}$
pyrophosphate	Ni <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	12.77	$1.7 \times 10^{-13}$
quinaldate	NiL <sub>2</sub>	10.1	$8 \times 10^{-11}$
8-quinolinolate	NiL <sub>2</sub>	26.1	$8 \times 10^{-27}$
selenite	NiSeO <sub>3</sub>	5.0	$1.0 \times 10^{-5}$
α-sulfide	α-NiS	18.50	$3.2 \times 10^{-19}$
β-sulfide	β-NiS	24.0	$1.0 \times 10^{-24}$
γ-sulfide	γ-NiS	25.70	$2.0 \times 10^{-26}$
Palladium			
(II) hydroxide	Pd(OH) <sub>2</sub>	31.0	$1.0 \times 10^{-31}$
(IV) hydroxide	Pd(OH) <sub>4</sub>	70.20	$6.3 \times 10^{-71}$
quinaldate	PdL <sub>2</sub>	12.90	$1.3 \times 10^{-13}$
thiocyanate	Pd(SCN) <sub>2</sub>	22.36	$4.39 \times 10^{-23}$
Platinum			
(IV) bromide	PtBr <sub>4</sub>	40.50	$3.2 \times 10^{-41}$
(II) hydroxide	Pt(OH) <sub>2</sub>	35	$1 \times 10^{-35}$
Plutonium			
(III) fluoride	PuF <sub>3</sub>	15.60	$2.5 \times 10^{-16}$
(IV) fluoride	PuF <sub>4</sub>	19.20	$6.3 \times 10^{-20}$
(IV) hydrogen phosphate	Pu(HPO <sub>4</sub> ) <sub>2</sub> · xH <sub>2</sub> O	27.7	$2 \times 10^{-28}$
(III) hydroxide	Pu(OH) <sub>3</sub>	19.70	$2.0 \times 10^{-20}$
(IV) hydroxide	Pu(OH) <sub>4</sub>	55	$1 \times 10^{-55}$
(IV) iodate	Pu(IO <sub>3</sub> ) <sub>4</sub>	12.3	$5 \times 10^{-13}$
(VI) carbonate	PuO <sub>2</sub> CO <sub>3</sub>	12.77	$1.7 \times 10^{-13}$
(V) hydroxide	PuO <sub>2</sub> (OH)	9.3	$5 \times 10^{-10}$
(VI) hydroxide	PuO <sub>2</sub> (OH) <sub>2</sub>	24.7	$2 \times 10^{-25}$
Polonium			
sulfide	PoS	28.26	$5.6 \times 10^{-29}$
Potassium			
hexabromoplatinate	K <sub>2</sub> [PtBr <sub>6</sub> ]	4.20	$6.3 \times 10^{-5}$
hexachloropalladate	K <sub>2</sub> [PdCl <sub>6</sub> ]	5.22	$6.0 \times 10^{-6}$
hexachloroplatinate	K <sub>2</sub> [PtCl <sub>6</sub> ]	5.13	$7.48 \times 10^{-6}$
hexafluoroplatinate	K <sub>2</sub> [PtF <sub>6</sub> ]	4.54	$2.9 \times 10^{-5}$

TABLE 8.6 Solubility Product Constants (*Continued*)

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

TABLE 8.6 Solubility Product Constants (Continued)

Compound	Formula	$pK_{sp}$	$K_{sp}$
iodide	AgI	16.07	$8.52 \times 10^{-17}$
molybdate	$Ag_2MoO_4$	11.55	$2.8 \times 10^{-12}$
nitrite	AgNO <sub>2</sub>	3.22	$6.0 \times 10^{-4}$
oxalate	$Ag_2C_2O_4$	11.27	$5.40 \times 10^{-12}$
phosphate	$Ag_3PO_4$	16.05	$8.89 \times 10^{-17}$
quinaldate	AgL	16.89	$1.3 \times 10^{-17}$
perrhenate	AgReO <sub>4</sub>	4.10	$8.0 \times 10^{-5}$
selenate	$Ag_2SeO_4$	7.25	$5.7 \times 10^{-8}$
selenite	$Ag_2SeO_3$	15.00	$1.0 \times 10^{-15}$
selenocyanate	AgSCN	15.40	$4.0 \times 10^{-16}$
sulfate	$Ag_2SO_4$	4.92	$1.20 \times 10^{-5}$
sulfite	$Ag_2SO_3$	13.82	$1.50 \times 10^{-14}$
sulfide	$Ag_2S$	49.20	$6.3 \times 10^{-50}$
thiocyanate	AgSCN	11.99	$1.03 \times 10^{-12}$
vanadate	AgVO <sub>3</sub>	6.3	$5 \times 10^{-7}$
tungstate	$Ag_2WO_4$	11.26	$5.5 \times 10^{-12}$
Sodium			
ammonium cobaltinitrite	$Na(NH_4)_2[Co(NO_2)_6]$	10.66	$2.2 \times 10^{-11}$
antimonate	$Na[Sb(OH)_6]$	7.4	$4 \times 10^{-8}$
hexafluoroaluminate	$Na_2[AlF_6]$	9.39	$4.0 \times 10^{-10}$
uranyl arsenate	$NaUO_2AsO_4$	21.87	$1.3 \times 10^{-22}$
Strontium			
arsenate	$Sr_3(AsO_4)_2$	18.37	$4.29 \times 10^{-19}$
carbonate	SrCO <sub>3</sub>	9.25	$5.60 \times 10^{-10}$
chromate	SrCrO <sub>4</sub>	4.65	$2.2 \times 10^{-5}$
fluoride	SrF <sub>2</sub>	8.36	$4.33 \times 10^{-9}$
iodate	Sr(IO <sub>3</sub> ) <sub>2</sub>	6.94	$1.14 \times 10^{-7}$
iodate hydrate	$Sr(IO_3)_2 \cdot H_2O$	6.42	$3.77 \times 10^{-7}$
molybdate	SrMoO <sub>4</sub>	6.7	$2 \times 10^{-7}$
niobate	$Sr(NbO_3)_2$	17.38	$4.2 \times 10^{-18}$
oxalate hydrate	$SrC_2O_4 \cdot H_2O$	6.80	$1.6 \times 10^{-7}$
phosphate	$Sr_3(PO_4)_2$	27.39	$4.0 \times 10^{-28}$
8-quinolinolate	SrL <sub>2</sub>	9.3	$5 \times 10^{-10}$
selenate	SrSeO <sub>4</sub>	3.09	$8.1 \times 10^{-4}$
selenite	SrSeO <sub>3</sub>	5.74	$1.8 \times 10^{-6}$
sulfate	SrSO <sub>4</sub>	6.46	$3.44 \times 10^{-7}$
sulfite	SrSO <sub>3</sub>	7.4	$4 \times 10^{-8}$
tungstate	SrWO <sub>4</sub>	9.77	$1.7 \times 10^{-10}$
Terbium			
hydroxide	Tb(OH) <sub>3</sub>	21.70	$2.0 \times 10^{-22}$
Tellurium			
hydroxide	Te(OH) <sub>4</sub>	53.52	$3.0 \times 10^{-54}$
Thallium(I)			
azide	TlN <sub>3</sub>	3.66	$2.2 \times 10^{-4}$
bromate	TlBrO <sub>3</sub>	4.96	$1.10 \times 10^{-5}$
bromide	TlBr	5.43	$3.71 \times 10^{-6}$
chloride	TlCl	3.73	$1.86 \times 10^{-4}$
chromate	Tl <sub>2</sub> CrO <sub>4</sub>	12.06	$8.67 \times 10^{-13}$
ferrocyanide dihydrate	$Tl_4[Fe(CN)_6] \cdot 2H_2O$	9.3	$5 \times 10^{-10}$
hexachloroplatinate	$Tl_2[PtCl_6]$	11.40	$4.0 \times 10^{-12}$
iodate	TlIO <sub>3</sub>	5.51	$3.12 \times 10^{-6}$
iodide	TlI	7.26	$5.54 \times 10^{-8}$

TABLE 8.6 Solubility Product Constants (*Continued*)

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



**TABLE 8.6** Solubility Product Constants (*Continued*)

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

### 8.2.1 Proton-Transfer Reactions

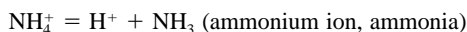
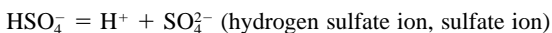
The  $pK_a$  values listed in Tables 8.7 and 8.8 are the negative (decadic) logarithms of the acidic dissociation constant, i.e.,  $-\log_{10} K_a = pK_a$ . For the general proton-transfer reaction



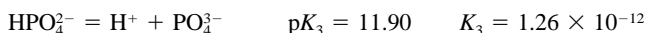
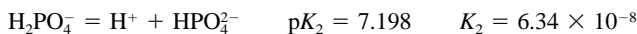
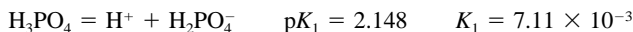
the acidic dissociation constant is formulated as follows:

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

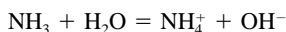
The most common charge types for the acid HB and its conjugate base B are



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



If the basic dissociation constant  $K_b$  for the equilibrium such as



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 $Ce(OH)_2^+$	-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	

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

Substance	Formula or remarks	pK <sub>1</sub>	pK <sub>2</sub>
Hydrazinium(2+) ion	$^+H_3N-NH_3^+$	0.27	7.94(3)
Hydrogen amidodisulfonate	$HNSO(OH)_2$	pK <sub>3</sub> 8.50	
Hydrogen amidophosphate	$H_2NPO(OH)_2$ (26°C)	2.739	8.102
Hydrogen arsenate	$H_3AsO_4$	2.223	6.760
Hydrogen- <i>d</i> <sub>3</sub> arsenate	$D_3AsO_4$	2.596	
Hydrogen arsenite	$HAsO_2$	9.28(10)	
Hydrogen azide	$HN_3$	4.62	
Hydrogen- <i>d</i> 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- <i>d</i> 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- <i>d</i> 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	$(HO)_2PO(NH)PO(OH)(NH)PO(OH)_2$ $\mu = 0.1$	$\sim 1$	$\sim 2$
		pK <sub>3</sub> 3.03	pK <sub>4</sub> 6.61
		pK <sub>5</sub> 9.84	
Hydrogen diphosphate	$H_4P_2O_7$	0.91	2.10
		pK <sub>3</sub> 6.70	pK <sub>4</sub> 9.35
		-12	-8
Hydrogen disulfate	$H_2S_2O_7$ (theoretical prediction)	-3.4	-0.2
Hydrogen dithionate	$H_2S_2O_6$	0.35	2.45
Hydrogen dithionite	$H_2S_2O_4$	3.20(4)	
Hydrogen fluoride	$H_2F_2$	9.01	12.30
Hydrogen germanate	$H_2GeO_4$		1.92
Hydrogen hexafluorosilicate	$H_2SiF_6$		2.50
Hydrogen hydrosulfite	$H_2S_2O_4$	0.35	
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	p <i>K</i> <sub>1</sub>	p <i>K</i> <sub>2</sub>
Hydrogen- <i>d</i> iodate	DIO <sub>3</sub> (in D <sub>2</sub> O)	1.15	
Hydrogen iodide	HI	−8.56	
Hydrogen manganate(VI)	H <sub>2</sub> MnO <sub>4</sub> (35°C) $\mu = 0.1$		10.15
Hydrogen nitrate	HNO <sub>3</sub>	−1.37(7)	
Hydrogen nitrite	HNO <sub>2</sub>	3.14(1)	
Hydrogen perchlorate	HClO <sub>4</sub>	−1.6	
Hydrogen periodate	HIO <sub>4</sub>	1.64	
Hydrogen peroxide	H <sub>2</sub> O <sub>2</sub>	11.64(2)	
Hydrogen peroxophosphate	H <sub>3</sub> PO <sub>5</sub> $\mu = 0.2$	1.1	5.5
		p <i>K</i> <sub>3</sub> 12.8	
Hydrogen peroxosulfate	H <sub>2</sub> SO <sub>5</sub>	1.0	9.86
Hydrogen perrhenate	HReO <sub>4</sub>	−1.25	
Hydrogen pertechnetate	HTcO <sub>4</sub>	0.3	
Hydrogen perthiocarbonate	H <sub>2</sub> CS <sub>4</sub>	3.54	7.24
Hydrogen perxenate	H <sub>4</sub> XeO <sub>6</sub>	p <i>K</i> <sub>3</sub> 10.5	
Hydrogen phosphate(3−)	H <sub>3</sub> PO <sub>4</sub>	2.148(20)	7.198(10)
		p <i>K</i> <sub>3</sub> 12.32(6)	
Hydrogen- <i>d</i> <sub>2</sub> phosphate	D <sub>2</sub> PO <sub>4</sub> (in D <sub>2</sub> O)	7.780	
Hydrogen phosphinate	H <sub>2</sub> PHO <sub>2</sub>	1.23	
Hydrogen phosphonate	H <sub>2</sub> PHO <sub>3</sub>	1.43	6.68(14)
Hydrogen selenate	H <sub>2</sub> SeO <sub>4</sub>		1.66
Hydrogen selenide	H <sub>2</sub> Se $\mu = 0.03$	3.89	11.0
Hydrogen selenite	H <sub>2</sub> SeO <sub>3</sub>	2.62	8.30(15)
Hydrogen silicate(4−)	H <sub>4</sub> SiO <sub>4</sub>	9.60(10)	11.8(1)
Hydrogen sulfamate	H <sub>2</sub> NSO <sub>3</sub> H	0.99	
Hydrogen sulfate	H <sub>2</sub> SO <sub>4</sub>		1.99(1)
Hydrogen sulfide	H <sub>2</sub> S	6.97	12.90
Hydrogen sulfite	SO <sub>2</sub> + H <sub>2</sub> O = HSO <sub>3</sub> <sup>−</sup> = H <sup>+</sup>	1.89	7.205
Hydrogen tellurate	H <sub>6</sub> TeO <sub>6</sub>	7.65(5)	11.00(5)
Hydrogen telluride	H <sub>2</sub> Te (18°C)	2.64	11–12
Hydrogen tellurite	H <sub>2</sub> TeO <sub>3</sub> (20°C)	6.27	8.43
Hydrogen tetrafluoroborate	BF <sub>4</sub> <sup>−</sup>	0.5	
Hydrogen tetracyanonickelate	H <sub>2</sub> Ni(CN) <sub>4</sub>	4.69	6.59
Hydrogen tetraperoxo-chromate	H <sub>3</sub> CrO <sub>8</sub> (30°C) $\mu = 3$	7.16	
Hydrogen tetrapolyphosphate	H <sub>4</sub> P <sub>4</sub> O <sub>13</sub> $\mu = 0.034$	1.99	2.64
		p <i>K</i> <sub>3</sub> 6.62	p <i>K</i> <sub>4</sub> 8.2

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

Substance	Formula or remarks	p <i>K</i> <sub>1</sub>	p <i>K</i> <sub>2</sub>
Hydrogen tetrathiophosphate	H <sub>3</sub> PS <sub>4</sub>	1.5	3.5
Hydrogen thiocyanate	HSCN $\mu = 3$	p <i>K</i> <sub>3</sub> 6.6 -1.8	
Hydrogen thiophosphate	H <sub>3</sub> PO <sub>3</sub> S	1.788	5.427
Hydrogen thiosulfate	H <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	p <i>K</i> <sub>3</sub> 10.08 0.6	1.74
Hydrogen tripolyphosphate	H <sub>3</sub> P <sub>3</sub> O <sub>9</sub>	~1 p <i>K</i> <sub>3</sub> 2.00(10) p <i>K</i> <sub>2</sub> 5.83(7) p <i>K</i> <sub>3</sub> 8.51(6)	1.7
Hydrogen triselenocarbonate	H <sub>2</sub> CSe <sub>3</sub>	1.16	7.70
Hydrogen trithiocarbonate	H <sub>2</sub> CS <sub>3</sub> (20°C)	2.68	8.18
Hydrogen tungstate	H <sub>2</sub> WO <sub>4</sub>	2.20	3.70
Hydrogen vanadate(-1)	HVO <sub>3</sub>	3.80	
Hydrogen vanadate(3-)	H <sub>3</sub> VO <sub>4</sub>	3.78	7.78(4)
Hydroxylamine- <i>N,N</i> -disulfonic acid	HON(SO <sub>3</sub> H) <sub>2</sub> $\mu = 1.6$	p <i>K</i> <sub>3</sub> 11.85	
Hydroxylamine <i>O</i> -sulfonate	<sup>+</sup> H <sub>3</sub> NOSO <sub>3</sub> <sup>-</sup> $\mu = 1$	1.48	
Imidodiphosphoric acid	(HO) <sub>2</sub> PO(NH)PO(OH) <sub>2</sub> $\mu = 0.2$	~2 p <i>K</i> <sub>3</sub> 7.08	2.85 p <i>K</i> <sub>4</sub> 9.72
Indium(III) ion	In <sup>3+</sup> hydrolysis	3.54	4.28
Iridium(III) ion	Ir <sup>3+</sup> hydrolysis $\mu = 1$	4.37	5.20
Iron(II) ion	Fe <sup>2+</sup> hydrolysis $\mu = 1$	6.8	
Iron(III) ion	Fe <sup>3+</sup> hydrolysis	2.19	
Lanthanum(III) ion	La <sup>3+</sup> hydrolysis	9.06	
Lead(II) ion	Pb <sup>2+</sup> hydrolysis $\mu = 0.3$	7.8	
Lead(IV) ion	Pb <sup>4+</sup> hydrolysis	1.8	3.2
Lithium(I) ion	Li <sup>+</sup>	13.8	
Lutetium(III) ion	Lu <sup>3+</sup> hydrolysis	7.94	
Magnesium(II) ion	Mg <sup>2+</sup> hydrolysis	11.41	
Manganese(II) ion	Mn <sup>2+</sup> hydrolysis	10.59	
Manganese(III) ion	Mn <sup>3+</sup> hydrolysis	0.4	
Mercury(I) ion	Hg <sub>2</sub> <sup>2+</sup> hydrolysis $\mu = 0.5$	5.0	
Mercury(II) ion	Hg <sup>2+</sup> hydrolysis $\mu = 0.5$	3.70	2.65
Neodymium(III) ion	Nd <sup>3+</sup> hydrolysis $\mu = 3$	9.0(5)	
Neptunium(III) ion	Np <sup>3+</sup> hydrolysis $\mu = 0.3$	7.43	
Neptunium(IV) ion	Np <sup>4+</sup> hydrolysis $\mu = 2$	2.30	
Neptunium(V) ion	NpO <sub>2</sub> <sup>+</sup> hydrolysis	8.90(2)	
Nickel(II) ion	Ni <sup>2+</sup> hydrolysis	9.86	
Osmium tetroxide	OsO <sub>4</sub> hydrolysis $\mu = 1$	12.1	
Palladium(II) ion	Pd <sup>2+</sup> (stepwise p <i>K</i> <sub>b</sub> values)	13.0	12.8
Pentacyanoaquoferrate(II) ion	Fe(CN) <sub>5</sub> (H <sub>2</sub> O) <sup>3-</sup> $\mu = 0.1$	2.63	

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

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

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

*Weak acid:* 
$$\text{pH} = \frac{1}{2}pK_a - \frac{1}{2} \log [\text{acid}]$$

*Weak base:* 
$$\text{pH} = 14.00 - \frac{1}{2}pK_b + \frac{1}{2} \log [\text{base}]$$

*Salt formed by a weak acid and a strong base:*

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

*Acid salts of a dibasic acid:*

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

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

$$\text{pH} = pK_a + \log \left( \frac{[\text{salt}] + [\text{H}_3\text{O}^+] - [\text{OH}^-]}{[\text{acid}] - [\text{H}_3\text{O}^+] + [\text{OH}^-]} \right)$$

### 8.2.1.2 Calculation of Concentrations of Species Present at a Given pH

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

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

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

⋮

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

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

Ionic strength  $\mu$  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)			
<i>N</i> -(2-Acetamido)-2-aminoethane-sulfonic 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			
<i>N</i> -(2-Acetamido)iminodiacetic acid (20°C)	6.62			
3-Acetamidopyridine	4.37(+1)			
Acetanilide	0.4(+1)	13.39(0) <sup>40°C</sup>		
Acetic acid	4.756			
Acetic acid- <i>d</i> (in D <sub>2</sub> O)	5.32			
Acetoacetic acid (18°C)	3.58			
Acetohydrazine	3.24(+1)			
Acetone oxime	12.2			
2-Acetoxybenzoic acid (acetylsalicylic acid)	3.48			
3-Acetoxybenzoic acid	4.00			
4-Acetoxybenzoic acid	4.38			
Acetylacetic acid (18°C)	3.58			
<i>N</i> -Acetyl- $\alpha$ -alanine	3.715			
<i>N</i> -Acetyl- $\beta$ -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			
<i>N</i> -Acetylcysteine (30°C)	9.52			
Acetylenedicarboxylic acid	1.75	4.40		
<i>N</i> -Acetylglycine	3.670			
<i>N</i> -Acetylguanidine	8.23(+1)			
<i>N</i> - $\alpha$ -Acetyl-L-histidine	7.08			
Acetylhydroxamic acid (20°C)	9.40			
<i>N</i> -Acetyl-2-mercaptoethylamine	9.92(SH)			
4-Acetyl- $\beta$ -mercaptoisoleucine (30°C)	10.30			
2-Acetyl-1-naphthol (30°C)	13.40			
<i>N</i> -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- <i>N</i> -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		
$\alpha$ -Alanine	2.34(+1)	9.69(0)		
$\beta$ -Alanine	3.55(+1)	10.238(0)		
$\alpha$ -Alanine, methyl ester ( $\mu = 0.10$ )	7.743(+1)			
$\beta$ -Alanine, methyl ester ( $\mu = 0.10$ )	9.170(+1)			
<i>N-D</i> -Alanyl- $\alpha$ - <i>D</i> -alanine ( $\mu = 0.1$ )	3.32(+1)	8.13(0)		
<i>N-L</i> -Alanyl- $\alpha$ - <i>L</i> -alanine ( $\mu = 0.1$ )	3.32(+1)	8.13(0)		
<i>N-L</i> -Alanyl- $\alpha$ - <i>D</i> -alanine	3.12(+1)	8.30(0)		
<i>N</i> - $\alpha$ -Alanylglycine	3.11(+1)	8.11(0)		
Alanylglycylglycine	3.190(+1)	8.15(0)		
$\beta$ -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-Aminoantipyrene	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- <i>N</i> -butyl-3-methyl-2-butanone oxime	9.09(+1)			
4-Aminobutylphosphonic acid	2.55	7.55	10.9	
2-Amino- <i>N</i> -carbamoylbutanoic acid	3.886(+1)			
4-Amino- <i>N</i> -carbamoylbutanoic acid	4.683(+1)			
2-Amino- <i>N</i> -carbamoyl-2-methylpropanoic 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- <i>N,N</i> -dihydroxyethyl-2-hydroxyl-1,3-propanediol	6.484(+1)			
2-Amino- <i>N,N</i> -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)aminoethyl]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- <i>N</i> -ethyl-3-methyl-2-butanone oxime	9.23(+1)			
<i>N</i> -(2-Aminoethyl)morpholine	4.06(+2)	9.15(+1)		
<i>p</i> -(2-Aminoethyl)phenol	9.3	10.9		
2-Aminoethylphosphonic acid	2.45(+1)	7.0(0)	10.8(-1)	
<i>N</i> -(2-Aminoethyl)piperidine (30°C)	6.38	9.89		
2-(2-Aminoethyl)pyridine ( $\mu = 0.5$ )	4.24(+2)	9.78(+1)		
4-Amino-3-ethylpyridine (20°C)	9.51(+1)			
<i>N</i> -(2-Aminoethyl)pyrrolidine (30°C)	6.56(+2)	9.74(+1)		
2-Amino-fluorine	10.34(+1)			
2-Amino- <i>D</i> - $\beta$ -glucose ( $\mu = 0.05$ )	2.20(+1)	9.08(0)		
2-Amino- <i>N</i> -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)		
<i>C</i> -Amino- <i>C</i> -hydrazinocarbonyl-methane	2.38(+2)	7.69(+1)		
2-Amino-3-hydroxybenzoic acid	2.5(+1)	5.192(0)	10.118(OH)	
<i>L</i> -2-Amino-3-hydroxybutanoic acid (threonine)	2.088(+1)	9.100(0)		
<i>DL</i> -2-Amino-4-hydroxybutanoic acid ( $\mu = 0.1$ )	2.265(+1)	9.257(0)		
<i>DL</i> -4-Amino-3-hydroxybutanoic acid ( $\mu = 0.1$ )	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- <i>N</i> -isopropyl-3-methyl-2-butanone oxime	9.09(+1)			
4-Amino-3-isopropylpyridine (20°C)	9.54(+1)			
1-Aminoisoquinoline (20°C, $\mu = 0.01$ )	7.62(+1)			
3-Aminoisoquinoline (20°C, $\mu = 0.005$ )	5.05(+1)			
4-Aminoisoxazolidine-3-one	7.4(+1)			
Aminomalonic acid	3.32(+1)	9.83(0)		
<i>DL</i> -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- <i>N</i> -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 ( $\mu =$ 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-Aminosalicylic acid	1.991(+1)	3.917(0)	13.74	
5-Aminosalicylic 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-trinitrofluorene		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-Asparaginyglycine		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
$\alpha$ -Aspartylhistidine (38°C, $\mu = 0.1$ )		3.02	6.82	7.98
$\beta$ -Aspartylhistidine (38°C, $\mu = 0.1$ )		2.95	6.93	8.72
N-Aspartyl- <i>p</i> -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)		
<i>m</i> -Benzbetaine	3.217(+1)			
<i>p</i> -Benzbetaine	3.245(+1)			
Benzenearsonic acid (22°C)		8.48(-1)		
Benzene-1-arsonic acid-4-carbox- ylic acid		4.22 (COOH)	5.59	
Benzeneboronic acid	13.7			
Benzene-1-carboxylic acid-2-phos- phoric acid		3.78	9.17	
Benzene-1-carboxylic acid-3-phos- phoric 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)			
Benzenhexacarboxylic 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- $\alpha$ -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		
<i>N</i> -Benzoylglycine (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 ( $\mu = 0.3$ )	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)		
<i>N,N'</i> -Bis(2-aminoethyl)-ethylenedi- amine (20°C)	3.32(+4)	6.67(+3)	9.20(+2)	9.92(+1)
<i>N,N</i> -Bis(2-hydroxyethyl)-2-ami- noethane sulfonic acid (BES) (20°C)	7.15			
<i>N,N</i> -Bis(2-hydroxyethyl)glycine (bicine) (20°C)	8.35			
Bis(2-hydroxyethyl)iminotris (hy- droxymethyl)methane (bis-tris)	6.46(+1)			
1,3-Bis[tris(hydroxymethyl)methyl- lamino]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			
<i>erythro</i> -2-Bromo-3-chlorosuccinic acid (19°C, $\mu = 0.1$ )	1.4	2.6		
<i>threo</i> -2-Bromo-chlorosuccinic acid (19°C, $\mu = 0.1$ )	1.5	2.8		
<i>trans</i> -2-Bromocinnamic acid	4.41			
3-Bromo-4-(dimethylam- ino)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- <i>p</i> -tolylphosphonic acid	1.81	7.15		
Brucine (15°C)	2.50(+2)	8.16(+1)		
2-Butanamine ( <i>sec</i> -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-Butanetetra-carboxylic acid	3.43	4.58	5.85	7.16
<i>cis</i> -2-Butenoic acid (isocrotonic acid)	4.44			
<i>trans</i> -2-Butenoic acid ( <i>trans</i> -cro- tonic acid) (35°C)	4.676			
3-Butenoic acid (vinylacetic acid)	4.68			
3-Butoxybenzoic acid (20°C)	4.25			
Butylamine	10.64(+1)			
<i>tert</i> -Butylamine	10.685(+1)			
4- <i>tert</i> -Butylaniline	3.78(+1)			
<i>N-tert</i> -Butylaniline	7.10(+1)			
Butylarsonic acid (18°C)	4.23	8.91		
2- <i>tert</i> -Butylbenzoic acid	3.57			
3- <i>tert</i> -Butylbenzoic acid	4.199			
4- <i>tert</i> -Butylbenzoic acid	4.389			
<i>N</i> -Butylethylenediamine	7.53(+2)	10.30(+1)		
<i>N</i> -Butylglycine	2.35(+1)	10.25(0)		
<i>tert</i> -Butylhydroperoxide	12.80			
1-( <i>tert</i> -Butyl)-2-hydroxybenzene	10.62			
1-( <i>tert</i> -Butyl)-3-hydroxybenzene	10.119			
1-( <i>tert</i> -Butyl)-4-hydroxybenzene	10.23			
Butylmethylamine	10.90(+1)			
2-Butyl-1-methyl-2-pyrroline	11.84(+1)			
4- <i>tert</i> -Butylphenylacetic acid	4.417			
Butylphosphinic acid	3.41			
<i>tert</i> -Butylphosphinic acid	4.24			
<i>tert</i> -Butylphosphonic acid	2.79	8.88		
1-Butylpiperidine ( $\mu = 0.02$ )	10.43(+1)			
2- <i>tert</i> -Butylpyridine	5.76(+1)			
3- <i>tert</i> -Butylpyridine	5.82(+1)			
4- <i>tert</i> -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- <i>tert</i> -Butylthiazole ( $\mu = 0.1$ )	3.00(+1)			
4- <i>tert</i> -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		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)	
<i>N</i> -Carbamoylacetic acid	3.64			
<i>N</i> -Carbamoyl- $\alpha$ -D-alanine	3.89(+1)			
<i>N</i> -Carbamoyl- $\beta$ -alanine	4.99(+1)			
DL- <i>N</i> -Carbamoylalanine	3.892(+1)			
<i>N</i> -Carbamoylglycine	3.876			
2-Carbamoylpyridine (20°C)	2.10(+1)			
3-Carbamoylpyridine	3.328(+1)			
4-Carbamoylpyridine (20°C)	3.61(+1)			
$\beta$ -Carboxymethylaminopropanoic acid	3.61(+1)	9.46(0)		
Chloroacetic acid	2.867			
<i>N</i> -(2'-Chloroacetyl)glycine	3.38(0)			
<i>cis</i> -3-Chloroacrylic acid (18°C, $\mu = 0.1$ )	3.32			
<i>trans</i> -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		
<i>trans</i> -2'-Chlorocinnamic acid	4.234			
<i>trans</i> -3'-Chlorocinnamic acid	4.294			
<i>trans</i> -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-hydroxy- benzene	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- <i>N</i> -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)		
<b>DL</b> -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			
<i>N</i> -Chloro- <i>p</i> -toluenesulfonamide	4.54(+1)			
3-Chloro- <i>o</i> -toluidine	2.49(+1)			
4-Chloro- <i>o</i> -toluidine	3.385(+1)			
5-Chloro- <i>o</i> -toluidine	3.85(+1)			
6-Chloro- <i>o</i> -toluidine	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)		
<i>cis</i> -Cinnamic acid	3.879			
<i>trans</i> -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)			
<i>o</i> -Cresol	10.26			
<i>m</i> -Cresol	10.00			
<i>p</i> -Cresol	10.26			
Cumene hydroperoxide	12.60			
Cupreine	7.63(+1)			
Cyanamide	10.27			
Cyanoacetic acid	2.460			
Cyanoaceto-hydrazide	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			
<i>trans</i> -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)			
<i>N</i> -(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			
<i>o</i> -Cyanophenoxyacetic acid	2.98			
<i>m</i> -Cyanophenoxyacetic acid	3.03			
<i>p</i> -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		
<i>cis</i> -1,2-Cyclobutanedicarboxylic acid	3.90	5.89		
<i>trans</i> -1,2-Cyclobutanedicarboxylic acid	3.79	5.61		
<i>cis</i> -1,3-Cyclobutanedicarboxylic acid	4.04	5.31		
<i>trans</i> -1,3-Cyclobutanedicarboxylic acid	3.81	5.28		
Cyclohexanecarboxylic acid	4.90			
1,1-Cyclohexanediactic acid	3.49	6.96		
<i>cis</i> -1,2-Cyclohexanediactic acid (20°C)	4.42	5.45		
<i>trans</i> -1,2-Cyclohexanediactic acid (20°C)	4.38	5.42		
<i>cis</i> -1,2-Cyclohexanediamine	6.43(+2)	9.93(+1)		
<i>trans</i> -1,2-Cyclohexanediamine	6.34(+2)	9.74(+1)		
1,1-Cyclohexanedicarboxylic acid	3.45			
<i>cis</i> -1,2-Cyclohexanedicarboxylic acid (20°C)	4.34	6.76		
<i>trans</i> -1,2-Cyclohexanedicarboxylic acid (20°C)	4.18	5.93		
<i>cis</i> -1,3-Cyclohexanedicarboxylic acid (16°C)	4.10	5.46		
<i>trans</i> -1,3-Cyclohexanedicarboxylic acid (19°C)	4.31	5.73		
<i>trans</i> -1,4-Cyclohexanedicarboxylic acid (16°C)	4.18	5.42		
1,3-Cyclohexanedione	5.26			
<i>cis,cis</i> -1,3,5-Cyclohexanetriamine	6.9(+3)	8.7(+2)	10.4(+1)	
Cyclohexanimine	9.15			
<i>cis</i> -4-Cyclohexene-1,2-dicarboxylic acid (20°C)	3.89	6.79		
<i>trans</i> -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-Cyclohexylenedinitrioloacetic 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			
<i>cis</i> -Cyclopentane-1-carboxylic acid-2-acetic acid	4.40	5.79		
<i>trans</i> -Cyclopentane-1-carboxylic acid-2-acetic acid	4.39	5.67		
Cyclopentane-1,2-diamine- <i>N,N',N'</i> -tetraacetic acid ( $\mu = 0.1$ )	—	—	—	10.20
Cyclopentane-1,1-dicarboxylic acid	3.23	4.08		
<i>cis</i> -Cyclopentane-1,2-dicarboxylic acid	4.43	6.67		
<i>trans</i> -Cyclopentane-1,2-dicarboxylic acid	3.96	5.85		
<i>cis</i> -Cyclopentane-1,3-dicarboxylic acid	4.26	5.51		
<i>trans</i> -Cyclopentane-1,3-dicarboxylic acid	4.32	5.42		
Cyclopentylamine	10.65(+1)			
1,1-Cyclopentylodiacetic acid	3.80	6.77		
<i>cis</i> -Cyclopentyl-1,2-diacetic acid	4.42	5.42		
<i>trans</i> -Cyclopentyl-1,2-diacetic acid	4.43	5.43		
Cyclopropanecarboxylic acid	4.827			
Cyclopropane-1,1-dicarboxylic acid	1.82	5.43		
<i>cis</i> -Cyclopropane-1,2-dicarboxylic acid	3.33	6.47		
<i>trans</i> -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	9.17(SH)		
L-(+)-Cysteine, methyl ester	6.56 (NH <sub>3</sub> <sup>+</sup> )	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-Diallylbarbituric 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- <i>N,N'</i> -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			
<i>rac</i> -2,3-Dibromosuccinic acid (20°C)	1.43	2.24		
<i>meso</i> -2,3-Dibromosuccinic acid (20°C)	1.51	2.71		
3,5-Dibromo- <i>p</i> -L-tyrosine	2.17(+1)	6.45(0)	7.60(-1)	
Dibutylamine	11.25(+1)			
Di- <i>sec</i> -butylamine	10.91(+1)			
2,6-Di- <i>tert</i> -butylpyridine	3.58(+1)			
<i>rac</i> -2,3-Di- <i>tert</i> -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- <i>p</i> -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			
<i>rac</i> -2,3-Dichlorosuccinic acid (20°C)	1.43	2.81		
<i>meso</i> -2,3-Dichlorosuccinic acid	1.49	2.97		
3,5-Dichloro- <i>p</i> -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)			
$\alpha$ -(Diethylamino)toluene	9.44(+1)			
<i>N,N</i> -Diethylaniline	6.56(+1)			
5,5-Diethylbarbituric acid (veronal)	8.020(0)			
<i>N,N</i> -Diethylbenzylamine	9.48(+1)			
Diethylguanide (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)
<i>N,N</i> -Diethylethylenediamine	7.70(+2)	10.46(+1)		
2,2-Diethylglutaric acid	3.62	7.12		
<i>N,N</i> -Diethylglycine	2.04(+1)	10.47(0)		
Diethylglycolic acid (18°C)	3.804			
Diethylmalonic acid	2.151	7.417		
Diethylmethylamine	10.43(+1)			
<i>rac</i> -2,3-Diethylsuccinic acid	3.63	6.46		



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

Substance	$pK_1$	$pK_2$	$pK_3$	$pK_4$
<i>meso</i> -2,3-Diethylsuccinic acid	3.54	6.59		
<i>N,N</i> -Diethyl- <i>o</i> -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)			
$\alpha$ -Dihydrolysergic acid	3.57	8.45		
$\gamma$ -Dihydrolysergic acid	3.60	8.71		
$\alpha$ -Dihydrolysergol	8.30			
$\beta$ -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) ( $\mu = 0.1$ )	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 ( $\beta$ -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- <i>p</i> -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)			
<i>N,N</i> -Di(2-hydroxyethyl)glycine	8.333			
Dihydroxymaleic acid	1.10			
Dihydroxymalic acid	1.92			
1,3-Dihydroxy-2-methylbenzene ( $\mu = 0.65$ )	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, $\mu = 0.65$ )	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-tetramethyl- benzene ( $\mu = 0.65$ )	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			
<i>threo</i> -1,4-Dimercapto-2,3-butane- diol	8.9			
<i>meso</i> -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)			
<i>N,N</i> -Dimethylaminocyclohexane	10.72(+1)			
4-Dimethylamino-2,3-dimethyl-1- phenyl-3-pyrazolin-5-one	4.18(+1)			
4-Dimethylamino-3,5-dimethylpyr- ridine (20°C)	8.15(+1)			
2-(Dimethylamino)ethanol	9.26(+1)			
2-[2-(Dimethyl- amino)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-isopropylpyr- ridine (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-methylpyri- dine (20°C)	8.68(+1)			
4-(Dimethylamino- phenyl)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	$pK_1$	$pK_2$	$pK_3$	$pK_4$
<i>N,N</i> -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)			
<i>N,N</i> -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 acid	4.41			
3,5-Dimethylbenzoic acid	4.302			
<i>N,N</i> -Dimethylbenzylamine	9.02(+1)			
Dimethylbiguanide	2.77(+1)	11.52		
2,2-Dimethylbutanoic acid (18°C)	5.03			
Dimethylchlorotetracycline ( $\mu = 0.01$ )	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			
<i>cis</i> -3,3-Dimethyl-1,2-cyclopropanedicarboxylic acid	2.34	8.31		
<i>trans</i> -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 ( $\mu = 0.1$ )	11.22			
<i>N,N</i> -Dimethylethylenediamine- <i>N,N</i> -diacetic acid	6.63	9.53		
<i>N,N'</i> -Dimethylethylenediamine- <i>N,N'</i> -diacetic acid	7.40	10.16		
<i>N,N</i> -Dimethylethylenediamine- <i>N,N'</i> -diacetic acid	5.99	9.97		
<i>N,N</i> -Dimethylglycine	2.146(+1)	9.940(0)		
Dimethylglycolic acid (18°C)	4.04			
<i>N,N</i> -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 (NH <sup>+</sup> )	3.20	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			
$\alpha,\alpha$ -Dimethylaloacetic 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			
<i>N,N'</i> -Dimethylpiperazine	4.630(+2)	8.539(+1)		
1,2-Dimethylpiperidine	10.22			
<i>cis</i> -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)			
<i>meso</i> -2,2-Dimethylsuccinic acid	3.77	5.936		
<i>rac</i> -2,2-Dimethylsuccinic acid	3.93	6.20		
<b>D</b> -2,3-Dimethylsuccinic acid	3.82	5.93		
<i>meso</i> -2,3-Dimethylsuccinic acid	3.67	5.30		
<i>rac</i> -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			
<i>N,N</i> -Dimethyl- <i>o</i> -toluidine	5.86(+1)			
<i>N,N</i> -Dimethyl- <i>p</i> -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-pyridinecarboxylic 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		
<i>meso</i> -2,2-Diphenylsuccinic acid	3.48			
<i>rac</i> -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			
Diphenylthiocarbazono	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)			
Ergometrine	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- <i>N,N'</i> -dimethyl- <i>N,N'</i> -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 ( <i>o</i> -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			
<i>N</i> -Ethylalanine	2.22(+1)	10.22(0)		
Ethylamine	10.63(+1)			
(3-Ethylamino)phenylphosphonic acid	1.1(+1)	4.90(0)	7.24(-1)	
<i>N</i> -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			
<i>S</i> -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- <i>N,N'</i> -diacetic acid	6.42	9.46		
Ethylenediamine- <i>N,N</i> -dimethyl- <i>N,N'</i> -diacetic acid	6.047	10.068		
Ethylenediamine- <i>N,N</i> -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- <i>N,N,N',N'</i> -tetraacetic acid ( $\mu = 0.1$ )	1.99	2.67	6.16	10.26
Ethylenediamine- <i>N,N,N',N'</i> -tetrapropanoic acid (30°C)	3.00	3.43	6.77	9.60
Ethylene glycol	14.22			
Ethyleneimine	8.04(+1)			
<i>cis</i> -Ethylene oxide dicarboxylic acid	1.93	3.92		
<i>trans</i> -Ethylene oxide dicarboxylic acid	1.93	3.25		
<i>N</i> -Ethylethylenediamine	7.63(+2)	10.56(+1)		
<i>N</i> -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)		
<i>N</i> -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)			
5-Ethylthioacetic acid	5.06			
<i>N</i> -Ethyl- <i>o</i> -toluidine	4.92(+1)			
<i>N</i> -Ethylveratramine	7.40(+1)			
$\beta$ -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			
<i>N</i> -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		
<b>D</b> -(-)-Fructose	12.03			
Fumaric acid	3.10	4.60		
2-Furancarboxylic acid (2-furoic acid)	3.164			
<b>D</b> -(+)-Galactose	12.35			
Galactose-1-phosphoric acid	1.00	6.17		
Glucoscorbic acid	4.26	11.58		
<b>D</b> -Gluconic acid	3.86			
$\alpha$ - <b>D</b> -(+)-Glucose	12.28			
$\alpha$ - <b>D</b> -Glucose-1-phosphate	1.11(0)	6.504(-1)		
<i>trans</i> -Glutaconic acid	3.77	5.08		
<b>D</b> -(-)-Glutamic acid	2.162(+1)	4.272(0)	9.358(-1)	
<b>L</b> -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- $\alpha$ -alanine	3.15(+1)	8.33(0)		
Glycylalanylalanine	3.38(+1)	8.10(0)		
N-Glycylasparagine	2.942			
Glycylaspartic 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			
<i>trans</i> -2-Hexenoic acid	4.74			
<i>trans</i> -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		
<b>DL</b> -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)	
<b>DI</b> -Homatropine	9.7(+1)			
<b>DI</b> -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- <i>N,N</i> -diacetic acid	<0.1	2.8	3.8	
Hydrazine- <i>N'</i> - <i>N'</i> -diacetic acid	2.40	3.12	7.32	
4-Hydrazinocarbonylpyridine (20°C)	1.82	3.52	10.79	
<i>N</i> -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	$pK_1$	$pK_2$	$pK_3$	$pK_4$
$\alpha$ -Hydroxyasparagine	2.28(+1)	7.20(0)		
$\beta$ -Hydroxyasparagine	2.09(+1)	8.29(0)		
Hydroxyaspartic acid	1.91(+1)	3.51(0)	9.11(-1)	
2-Hydroxybenzaldehyde (salicyl- aldehyde)	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-hy- droxybenzyl 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-Hydroxybenzotrile	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			
<i>trans</i> -2'-Hydroxycinnamic acid	4.614			
<i>trans</i> -3'-Hydroxycinnamic acid	4.40			
10-Hydroxycodine	7.12			
<i>cis</i> -2-Hydroxycyclohexane-1-car- boxylic acid	4.796			
<i>trans</i> -2-Hydroxycyclohexane-1- carboxylic acid	4.682			
<i>cis</i> -3-Hydroxycyclohexane-1-car- boxylic acid	4.602			
<i>trans</i> -3-Hydroxycyclohexane-1- carboxylic acid	4.815			
<i>cis</i> -4-Hydroxycyclohexane-1-car- boxylic acid	4.836			
<i>trans</i> -4-Hydroxycyclohexane-1- carboxylic acid	4.687			
1-Hydroxy-2,4-dihydroxymethyl- benzene	9.79			
<i>N</i> -(Hydroxyethyl)biguanide	2.8(+2)	11.53(+1)		
<i>N</i> -(2-Hydroxy- ethyl)ethylenediamine	7.21(+2)	10.12(+1)		
<i>N'</i> -(2-Hydroxyethyl)ethylenediam- ine- <i>N,N,N'</i> -triacetic acid	2.39	5.37	9.93	
<i>N</i> -(2-Hydroxyethyl)iminodiacetic acid ( $\mu = 0.1$ )	2.2	8.65		
<i>N</i> -(2-Hydroxyethyl)piperazine- <i>N'</i> - ethansulfonic acid (20°C)	7.55			
4'-(2-Hydroxyethyl)-1'-piperazine- propanesulfonic 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- $\beta$ -Hydroxyglutamic acid	2.09	4.18	9.20	
1-Hydroxy-4-hydroxymethylbenzene	9.84			
5-Hydroxy-2-(hydroxymethyl)-4H-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 ( $\mu = 0.1$ )	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		
<i>trans</i> -4-Hydroxyproline	1.818(+1)	9.662(0)		
Hydroxypropanedioic acid (tartaric 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- <i>N</i> -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)		
<b>DL</b> -Hydroxysuccinic acid (malic acid)	3.458	5.097		
<b>L</b> -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- $\alpha, \alpha, \alpha$ -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 ( $\mu = 0.1$ )	4.26(+1)	7.26(0)		
2-(4-Imidazolyl)ethylamine	5.784(+2)	9.756(+1)		
3-(4-Imidazolyl)propanoic acid ( $\mu = 0.16$ )	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, $\mu = 0.1$ )	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)	9.20(+1)	11.88(0)	
	(imidazole)	( $NH_3^+$ )	(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	$pK_1$	$pK_2$	$pK_3$	$pK_4$
Isobutylic acid (18°C)	4.79			
Isobutylamine	10.41(+1)			
Isochlorotetracycline	3.1(+1)	6.7(0)	8.3(-1)	
Isocreatine	2.84(+1)			
Isoglutamine	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)			
Isotretonecanol	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)
$\alpha$ -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- $\alpha$ -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)			
<i>trans</i> -2-Methoxycinnamic acid	4.462			
<i>trans</i> -3-Methoxycinnamic acid	4.376			
<i>trans</i> -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			
<i>N</i> -Methylalanine	2.22(+1)	10.19(0)		
<i>O</i> -Methylallothreonine ( $\mu = 0.1$ )	1.92(+1)	8.90(0)		
Methylamine	10.62(+1)			
2-( <i>N</i> -Methylamino)benzoic acid	1.93(+1)	5.34(0)		
3-( <i>N</i> -Methylamino)benzoic acid	—	5.10(0)		
4-( <i>N</i> -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-tetra-methylpyridine (20°C)	10.06(+1)			
<i>N</i> -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-( <i>N</i> -Methylbenzamido)pyridine	1.44(+1)			
3-( <i>N</i> -Methylbenzamido)pyridine	3.66(+1)			
4-( <i>N</i> -Methylbenzamido)pyridine	4.68(+1)			
2-Methylbenzimidazole ( $\mu = 0.16$ )	6.29(+1)			
2-Methylbenzoic acid ( <i>o</i> -toluic acid)	3.90			
3-Methylbenzoic acid	4.269			
4-Methylbenzoic acid	4.362			
<i>N</i> -Methyl-1-benzoyllecgonine	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			
( <i>E</i> )-2-Methyl-2-butendioic acid (mesaconic acid)	3.09	4.75		
3-Methyl-2-butenic acid	5.12			
( <i>E</i> )-2-Methyl-2-butenic acid (tiglic acid)	4.96			
( <i>Z</i> )-2-Methyl-2-butenic acid (angelic acid)	4.30			
4-Methylcarboxylphenol	8.47			
( <i>E</i> )-2-Methylcinnamic acid	4.500			
( <i>E</i> )-3-Methylcinnamic acid	4.442			
( <i>E</i> )-4-Methylcinnamic acid	4.564			
1-Methylcyclohexane-1-carboxylic acid	5.13			
<i>cis</i> -2-Methylcyclohexane-1-carboxylic acid	5.03			
<i>trans</i> -2-Methylcyclohexane-1-carboxylic acid	5.73			
<i>cis</i> -3-Methylcyclohexane-1-carboxylic acid	4.88			
<i>trans</i> -3-Methylcyclohexane-1-carboxylic acid	5.02			
<i>cis</i> -4-Methylcyclohexane-1-carboxylic acid	5.04			
<i>trans</i> -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		
5-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)		
$\alpha$ -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 ( $\mu = 0.005$ )	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-Methylisothiurea	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)			
<i>N</i> -Methylmorpholine	7.13(+1)			
2-Methyl-1-naphthoic acid	3.11			
<i>N</i> -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			
<i>cis</i> -3-Methyl-2-pentenoic acid	5.15			
<i>trans</i> -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- <i>o</i> -phthalic acid	3.18			
4-Methyl- <i>o</i> -phthalic acid	3.89			
<i>N</i> -Methylpiperazine ( $\mu = 0.1$ )	4.94(+2)	9.09(+1)		
2-Methylpiperazine	5.62(+2)	9.60(+1)		
<i>N</i> -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)			
<i>O</i> -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-( <i>S</i> -Methylthio)phenol	9.53			
4-( <i>S</i> -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)			
<i>O</i> -Methylthreonine	2.02(+1)	9.00(0)		
<i>O</i> -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-( <i>N</i> -Morpholino)ethanesulfonic acid (MES) (20°C)	6.15			
3-( <i>N</i> -Morpholino)-2-hydroxypropanesulfonic acid (37°C)	6.75			
3-( <i>N</i> -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-Naphthylsulfonic 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			
<i>trans</i> -2-Nitrocinnamic acid	4.15			
<i>trans</i> -3-Nitrocinnamic acid	4.12			
<i>trans</i> -4-Nitrocinnamic acid	4.05			
Nitroethane	8.57			
2-Nitrohydroquinone	7.63	10.06		
<i>N</i> -Nitroiminodiacetic acid	2.21	3.33		
3-Nitromesitol	8.984			
Nitromethane	10.12			
1-Nitro-6,7-phenanthroline ( $\mu = 0.2$ )	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 ( $\mu = 0.02$ )	-2.06(+1)			
3-Nitropyridine ( $\mu = 0.02$ )	0.79(+1)			
4-Nitropyridine ( $\mu = 0.02$ )	1.23(+1)			
<i>N</i> -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			
<b>DL</b> -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- <b>DD</b>	1.35	2.30	8.68	11.25
Octopine- <b>LD</b>	1.40	2.30	8.72	11.34
Octylamine	10.65(+1)			
<b>L</b> -(+)-Ornithine	1.94(+2)	8.65(+1)	10.76(0)	
Oxalic acid	1.271	4.272		
3,6-Oxaoctanedioic acid ( $\mu = 1.0$ )	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		
<i>N</i> -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)		
Phenosulfonophthalein	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			
<i>L</i> -3-Phenyl- $\alpha$ -alanine	1.83(+1)	9.12(0)		
3-Phenyl- $\alpha$ -alanine, methyl ester	7.05(+1)			
Phenylalanylarginine ( $\mu = 0.01$ )	2.66(+1)	7.57(0)	12.40(-1)	
Phenylalanylglycine ( $\mu = 0.01$ )	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)			
$\beta$ -Phenylethylboronic acid	10.0			
<i>DL</i> - $\alpha$ -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		
<i>O</i> -Phenylphosphorylserine	2.13(+1)	8.79		
<i>O</i> -Phenylphosphorylserylglycine	3.18(+1)	6.95(0)		
<i>O</i> -Phenylphosphoryl-L-seryl-L-leucine	3.16(+1)	7.12(0)		
<i>N</i> -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			
$\beta$ -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		
<i>O</i> -Phosphorylethanolamine	5.838(+1)	10.638(0)		
<i>O</i> -Phosphorylserylglycine	3.13	5.41	8.01	
<i>O</i> -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)			
<i>o</i> -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	
Piperidine	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	$pK_1$	$pK_2$	$pK_3$	$pK_4$
<i>N</i> -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			
<i>N</i> -Propylalanine	2.21(+1)	10.19(0)		
Propylamine	10.568(+1)			
Propylarsonic acid (18°C)	4.21	9.09		
Propylenimine	8.18(+1)			
<i>N</i> -Propylglycine ( $\mu = 0.1$ )	2.38(+1)	10.03(0)		
<i>L</i> -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)			
<i>N</i> -Propylveratramine	7.20(+1)			
2-Propynoic acid	1.887			
Pseudoecgonine	9.70			
Pseudoisocyanine ( $\mu = 0.2$ )	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 ( $\mu = 0.15$ )	<2.5	4.14	6.20	8.69
Pyridoxamine ( $\mu = 0.1$ )	3.37(+2)	8.01(+1)	10.13(ring OH)	
Pyridoxamine-5-phosphate ( $\mu = 0.15$ ; $pK_5$ 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 <sub>6</sub> ) (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 ( $\mu =$ 0.16)	5.58(+1)			
2-(2'-Pyridyl)imidazole ( $\mu =$ 0.005)	8.98(+1)			
4-(2'-Pyridyl)imidazole ( $\mu = 0.1$ )	5.49(+1)			
Pyrimidine	1.30(+1)			
2,4(1 <i>H</i> ,3 <i>H</i> )-Pyrimidinedione (ura- cil)	0.6(+1)	9.46(0)		
2,4,5,6(1 <i>H</i> ,3 <i>H</i> )-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 (pro- line)	1.952(+1)	10.640(0)		
2-[2-( <i>N</i> -Pyrrolidinyl)ethyl]pyridine	3.60(+2)	9.39(+1)		
3-[2-( <i>N</i> -Pyrrolidinyl)ethyl]pyridine	4.28(+2)	9.28(+1)		
4-[2-( <i>N</i> -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)			
<b>D</b> -Raffinose	12.74			
Riboflavin (vitamin B <sub>2</sub> ) ( $\mu = 0.01$ )	ca -0.2	9.69		
$\alpha$ - <b>D</b> -Ribofuranose	12.11			
<b>D</b> -Ribose-5'-phosphonic acid	—	6.70(-1)	13.05(-2)	
<b>D</b> -Saccharic acid	5.00(0)			
Saccharin ( <i>o</i> -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 ( $\mu = 0.16$ )	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 ( $\mu = 0.1$ )	0.8(+1)			
Semicarbazide ( $\mu = 0.1$ )	3.53(+1)			
<b>L</b> -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			
$\beta$ -(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	
Tetradehydrohombine	10.59(+1)			
Tetraethylenepentamine [ $\mu = 0.1$ ; $pK_2$ 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 ( $\mu = 0.5$ )	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-Thenoyltrifluoroacetone	5.70(0)			
Theobromine	0.68(+1)	7.89		
Theophylline	<1(+1)	8.80		
Thiazoline	2.53(+1)			
Thioacetic acid	3.33			
<i>o</i> -Thiocresol	6.64			
<i>m</i> -Thiocresol	6.58			
<i>p</i> -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- <i>S</i> -methylcarbazide ( $\mu = 0.1$ )	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 ( $\mu = 0.1$ )	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		
<i>p</i> -Toluenesulfinic acid	1.7			
Tolhydroquinone	10.03	11.62		
<i>o</i> -Toluidine	4.45(+1)			
<i>m</i> -Toluidine	4.71(+1)			
<i>p</i> -Toluidine	5.08(+1)			
<i>o</i> -Tolylacetic acid (18°C)	4.36			
<i>p</i> -Tolylacetic acid (18°C)	4.36			
<i>o</i> -Tolylarsonic acid	3.82	8.85		
<i>m</i> -Tolylarsonic acid	3.82	8.60		
<i>p</i> -Tolylarsonic acid	3.70	8.68		
<i>o</i> -Tolylphosphonic acid	2.10	7.68		
<i>m</i> -Tolylphosphonic acid	1.88	7.44		
<i>p</i> -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 <i>H</i> -1,2,3-Triazole	—	9.26		
1 <i>H</i> -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			
Tribromoacetic 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			
$\alpha,\alpha,\alpha$ -Trifluoro- <i>m</i> -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 [ <b>D</b> -(-)-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 ( $\mu = 0.5$ )	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 ( $\mu = 0.1$ )	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 ( $\mu = 0.1$ )	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 ( $\mu = 0.01$ )	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)
$\alpha$ -Ureidobutanoic acid	3.886(0)			
$\gamma$ -Ureidobutanoic acid	4.683(0)			
$\beta$ -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'-uri- dylic 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	$pK_1$	$pK_2$	$pK_3$	$pK_4$
<b>DL</b> -Valine	2.32(+1)	9.61(0)		
<b>L</b> -Valine	2.296(+1)	9.79(0)		
Valine amide ( $\mu = 0.2$ )	8.00			
<b>L</b> -Valine, methyl ester	7.49(+1)			
<b>L</b> -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 <sub>12</sub>	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)
<b>D</b> -(+)-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  
 $pK_{\text{auto}}$ , negative logarithm (base 10) of autoprotolysis constant  
 $pK_{\text{sp}}$ , 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
<b>DL</b> - <i>N</i> -Acetylalanine (+ 1)		3.699	3.699	3.703	3.708	3.715	3.725	3.733	3.745	3.774
$\beta$ -Acetylaminopropionic (+ 1)		4.479	4.465	4.465	4.449	4.445	4.444	4.443	4.445	4.457
<i>N</i> -Acetylglycine (+ 1)		3.682	3.676	3.673	3.667	3.670	3.673	3.678	3.685	3.706
$\alpha$ -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 <sup>37.5°C</sup>		2.297
(0)			10.530			9.380		9.518 <sup>37.5°C</sup>		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 <sup>1°C</sup>		2.338 <sup>12.5°C</sup>			2.320		2.317 <sup>37.5°C</sup>		2.332
(0)	10.460 <sup>1°C</sup>		10.100 <sup>12.5°C</sup>			9.758		9.439 <sup>37.5°C</sup>		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 <sup>1°C</sup>		2.380 <sup>12.5°C</sup>			2.357		2.351 <sup>37.5°C</sup>		2.356
(0)	10.960 <sup>1°C</sup>		10.580 <sup>12.5°C</sup>			10.205		9.872 <sup>37.5°C</sup>		9.561
2-Aminopentanoic acid (+ 1)	2.376 <sup>1°C</sup>		2.347			2.318			2.309	2.313
(0)	10.508 <sup>1°C</sup>			10.154 <sup>12.5°C</sup>		9.808		9.490 <sup>37.5°C</sup>		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	
Bromopropionic acid (0)			1.786	1.814	1.839	1.855	1.879	1.900	1.919	

3- <i>tert</i> -Butylbenzoic acid (0)				4.266	4.231	4.199	4.170	4.143	4.119	
4- <i>tert</i> -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
<b>DL</b> - <i>N</i> -Carbamoylalanine (+ 1)		3.898	3.894	3.891	3.890	3.892	3.896	3.902	3.908	3.931
<i>N</i> -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	
<i>N,N'</i> -Dimethylethylenamine-										
<i>N,N'</i> -diacetic acid										
(0)	6.294		6.169		6.047		5.926		5.803	
(- 1)	10.446		10.268		10.068		9.882		9.684	
<i>N,N</i> -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 <sup>12.5°C</sup>			3.831		3.833 <sup>37.5°C</sup>		3.849
Glycylasparagine (+1)		2.968	2.958	2.952	2.943	2.942	2.942	2.944	2.947	2.959
<i>N</i> -Glycylglycine (+1)	3.201					3.126				3.159
			8.594 <sup>12.5°C</sup>			8.252		7.948 <sup>37.5°C</sup>		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 <sup>1°C</sup>		1.850 <sup>12.5°C</sup>			1.818		1.798 <sup>37.5°C</sup>		1.796
(0)	10.274 <sup>1°C</sup>		9.958 <sup>12.5°C</sup>			9.662		9.394 <sup>37.5°C</sup>		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
<b>DL</b> -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		
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		
<b>DL</b> -Isoleucine (+ 1)	2.365		2.338 <sup>12.5°C</sup>			2.318		2.317 <sup>37.5°C</sup>		2.332
(0)	10.460		10.100 <sup>12.5°C</sup>			9.758		9.439 <sup>37.5°C</sup>		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, p <i>K</i> <sub>sp</sub>	8.01			7.87		7.80		7.73		7.63
<b>DL</b> -Leucine (+ 1)	2.383 <sup>1°C</sup>		2.348 <sup>12.5°C</sup>			2.328		2.327 <sup>37.5°C</sup>		2.333
(0)	10.458 <sup>1°C</sup>		10.095 <sup>12.5°C</sup>			9.744		9.434 <sup>37.5°C</sup>		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, p <i>K</i> <sub>sp</sub>			18.65	18.48	18.27	17.88		16.79		
Methanol (solvent), p <i>K</i> <sub>auto</sub>		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
Nitritotriacetic 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		
<b>DL-Norleucine</b>										
(+1)	2.394		2.356 <sup>12.5°C</sup>			2.335		2.324 <sup>37.5°C</sup>		2.328
(0)	10.564		10.190 <sup>12.5°C</sup>			9.834		9.513 <sup>37.5°C</sup>		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
<i>o</i> -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
<b>Proline</b>										
(+1)	2.011		1.964 <sup>12.5°C</sup>			1.952		1.950 <sup>37.5°C</sup>		1.958
(0)	11.296		10.972 <sup>12.5°C</sup>			10.640		10.342 <sup>37.5°C</sup>		10.064
Propenoic acid (0)				4.267	4.250	4.247	4.249	4.267	4.301	

<i>N</i> -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 <sup>1°C</sup>		2.232 <sup>12.5°C</sup>			2.186		2.154 <sup>37.5°C</sup>		2.132
(0)	9.880 <sup>1°C</sup>		9.542 <sup>12.5°C</sup>			9.208		8.904 <sup>37.5°C</sup>		8.628
Silver bromide, p <i>K</i> <sub>sp</sub>		13.33		12.83	12.57	12.30	12.07	11.83	11.61	11.19
Silver chloride, p <i>K</i> <sub>sp</sub>		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 <sup>4,3°C</sup>		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
<b>D</b> -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 <sup>1°C</sup>		2.132 <sup>12.5°C</sup>			2.088		2.070 <sup>37.5°C</sup>		2.055
(0)	9.748 <sup>1°C</sup>		9.420 <sup>12.5°C</sup>			9.100		8.812 <sup>37.5°C</sup>		8.548
<i>o</i> -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 acid (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	
$\beta$ -Ureidopropionic acid (0)		4.514	4.505	4.497	4.490	4.487	4.486	4.486	4.488	4.500
<b>DL</b> -Valine										
(+ 1)	2.320		2.297 <sup>12.5°C</sup>			2.296		2.292 <sup>37.5°C</sup>		2.310
(0)	10.413		10.064 <sup>12.5°C</sup>			9.719		9.405 <sup>37.5°C</sup>		9.124

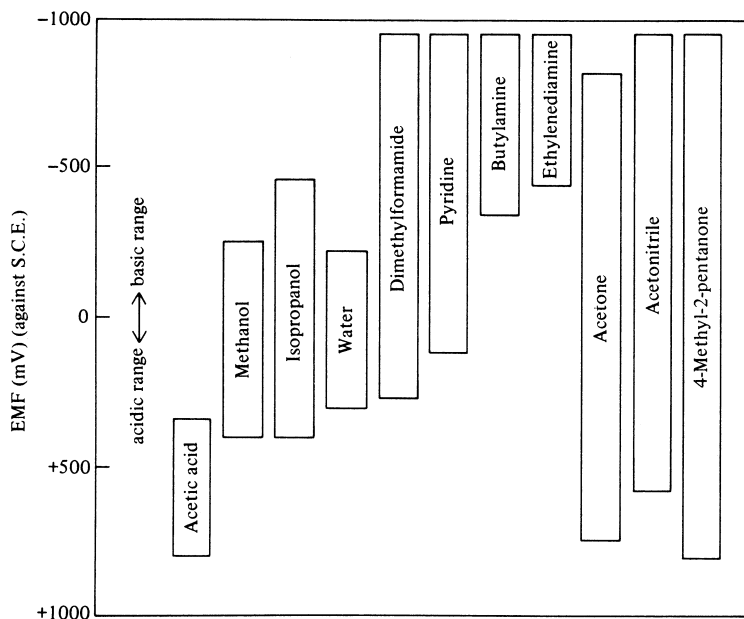


FIGURE 8.1 Approximate potential ranges in nonaqueous solvents.

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°)
<i>n</i> -Butanol	900		17.1
<i>n</i> -Butylamine	500		4.88(20°)
Chlorobenzene	1500		5.62
<i>N,N</i> -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 <sup>a</sup> , 9.75 <sup>d</sup>
<i>p</i> -Aminobenzoic acid	10.25		
Ammonium ion	10.7		6.40 <sup>b</sup>
Anilinium ion	6.0	5.70	
Benzoic acid		10.72	10.0 <sup>a</sup>
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- <i>n</i> -butylammonium ion			10.3 <sup>a</sup>
<i>o</i> -Chloroanilinium ion	3.4		
Cyanoacetic acid		7.49	
2,5-Dichloroanilinium ion			9.48 <sup>b</sup>
Dimethylaminoazobenzene		5.2	6.32 <sup>b</sup>
<i>N,N'</i> -Dimethylanilinium ion		4.37	
Formic acid		9.15	
Hydrobromic acid			5.5 <sup>c</sup>
Hydrochloric acid			8.55 <sup>b</sup> , 8.9 <sup>c</sup>
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	
<i>o</i> -Nitrobenzoic acid	7.6		
<i>m</i> -Nitrobenzoic acid	8.3		
<i>p</i> -Nitrobenzoic acid	8.4		
Perchloric acid			4.87 <sup>b</sup>
Phenol	14.0		
Phenol red	12.8	13.4	
Phthalic acid, $pK_2$	11.65		11.5 <sup>d</sup> , 6.10 <sup>d</sup> ( $pK_1$ )
Picric acid	3.8	3.8	8.9 <sup>c</sup>
Pyridinium ion			6.1 <sup>b</sup>
Salicylic acid	8.7	7.9	
Stearic acid	10.0		
Succinic acid, $pK_2$	11.4		
Sulfuric acid, $pK_1$			7.24 <sup>b,c</sup>
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		
<i>p</i> -Toluenesulfonic acid			8.44 <sup>b</sup>
<i>p</i> -Toluidinium ion		6.24	
Tribenzylammonium ion			5.40 <sup>b</sup>
Tropeoline 00	2.2		
Urea (protonated cation)			6.96 <sup>b</sup>
Veronal	12.6		

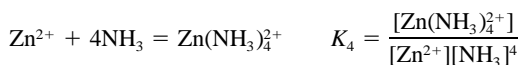
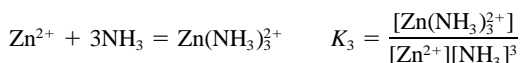
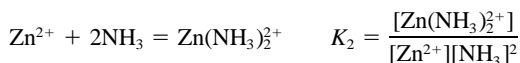
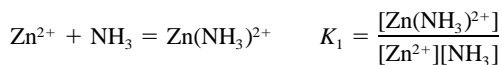
<sup>a</sup> Dimethylsulfoxide. <sup>b</sup> Glacial acetic acid. <sup>c</sup> Acetonitrile. <sup>d</sup> Acetone + 10% water.

### 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:



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:



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

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
<b>Ammonia</b>						
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		
<b>Bromide</b>						
Astatine	2.51 [AtBr]					
Bismuth(III)	4.30	5.55	5.89	7.82		9.70
Bromine	1.24 [Br <sub>3</sub> <sup>-</sup> ]					
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					
<b>Chloride</b>						
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		
<b>Cyanide</b>						
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		
<b>Fluoride</b>						
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 <sup>+</sup> ]	6.44					
Thorium	7.65	13.46	17.97			
Titanium(IV) [TiO <sup>2+</sup> ]	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			
<b>Hydroxide</b>						
Aluminum	9.27			33.03		
Antimony(III)		24.3	36.7	38.3		
Arsenic [as AsO <sup>+</sup> ]	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 $\text{PuO}_2^{2+}$ ]	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 $\text{UO}_2^{2+}$ ]	9.5	22.80		32.4		
Vanadium(III)	11.1	21.6				
Vanadium(IV) [as $\text{VO}^{2+}$ ]	8.6		[25.8 for $\text{V}_2\text{O}_4(\text{OH})^-$ ]			
Vanadium(V) [as $\text{VO}^{3+}$ ]		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		
<b>Iodide</b>						
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		
<b>Iodate</b>						
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 $K_6$
<b>Nitrate</b>						
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		
<b>Pyrophosphate</b>						
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				
<b>Sulfate</b>						
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			
<b>Sulfite</b>						
Copper(I)	7.5	8.5	9.2			
Mercury(II)		22.66				
Silver	5.30	7.35				
<b>Thiocyanate</b>						
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					
<b>Thiosulfate</b>						
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 $K_4$
<b>Acetate</b>				
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) <i>a</i>	2.16	3.20		
Fe(II) <i>c</i>	3.2	6.1	8.3	
Fe(III) <i>a,d</i>	3.2			
In(III)	3.50	5.95	7.90	9.08
Hg(II)		8.43		
La(III) <i>a,e</i>	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 <i>a,e</i>	1.6–1.9	2.8–3.0	3.3–3.7	
Sr(II)	0.44			
Tl(III)				15.4
UO <sub>2</sub> (II) <i>a,e</i>	2.38	4.36	6.34	
Y(III) <i>a,e</i>	1.53	2.65	3.38	
Zn(II)	1.5			
<b>Acetylacetonone</b>				
Al(III) <i>b</i>	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) <i>b</i>	6.03	10.70	14.04	
Er(III) <i>b</i>	5.99	10.67	14.09	
Eu(III) <i>b</i>	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) <i>b</i>	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) <i>b</i>	5.1	8.90	11.90	
Lu(III) <i>b</i>	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) <i>a</i>	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) <i>b</i>	16.2	27.1		
Pr(III) <i>b</i>	5.4	9.5	12.5	
Pu(IV) <i>c</i>	10.5	19.7	28.1	34.1
Sc(III) <i>b</i>	8.0	15.2		
Sm(III) <i>b</i>	5.9	10.4		
Tb(III) <i>b</i>	6.02	10.63	14.04	
Th(IV)	8.8	16.2	22.5	26.7
Tm(IV) <i>b</i>	6.09	10.85	14.33	
U(IV) <i>a,c</i>	8.6	17.0	23.4	29.5
UO <sub>2</sub> (II) <i>b</i>	7.74	14.19		
VO(II)	8.68	15.79		
V(II)	5.4	10.2	14.7	
Y(III) <i>b</i>	6.4	11.1	13.9	
Yb(III) <i>b</i>	6.18	11.04	13.64	
Zn(II) <i>b</i>	4.98	8.81		
Zr(IV)	8.4	16.0	23.2	30.1
<b>Alizarin red</b>				
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 <sub>2</sub> (II)	4.22			
V(V)		8.6		
W(VI)		7.8		
<b>Arsenazo</b>				
Hf(IV)	10.07			
Zr(IV)	12.95			
<b>Aurintricarboxylic acid</b>				
Be(II)	4.54			
Cu(II)	4.1	8.81		
Fe(III)	4.68			
Th(IV)	5.04			
UO <sub>2</sub> (II)	4.77			
<b>Benzoylacetone (75% dioxane)</b>				
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 <sub>2</sub> (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 $K_4$	
<b>Calmagite</b>								
Ca	6.05							
Mg	8.05							
	Complex of HL <sup>2-</sup> Anion		Complex of L <sup>3-</sup> Anion		Complex of H <sub>2</sub> L <sup>-</sup>			
	log $K_1$	log $K_2$	log $K_1$	log $K_2$	log $K_3$			
<b>Citric acid</b>								
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 <sub>2</sub>	8.5	10.8						
Y					3.6			
Yb				8				
Zn	4.71		11.4					
	log $K_1$		log $K_2$		log $K_3$			
<b>1,2-Diaminocyclohexane-<i>N,N,N',N'</i>-tetraacetic acid</b>								
Al <i>c</i>	17.63							
Ba <i>c</i>	8.64							
Ca <i>c</i>	12.3							
Cd <i>c</i>	19.88							
Ce(III) <i>c</i>	16.76							
Co(II) <i>c</i>	19.57							
Cu(II) <i>c</i>	21.95							
Dy(III) <i>c</i>	19.69							
Er(III) <i>c</i>	20.20							
Eu(III) <i>c</i>	18.77							
Fe(III) <i>c</i>	27.48							
Ga <i>c</i>	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 <i>c</i>	18.80			
Hg(II) <i>c</i>	24.4			
Ho <i>c</i>	19.89			
La <i>c</i>	16.35			
Lu <i>c</i>	21.51			
Mg <i>c</i>	10.41			
Mn(II) <i>c</i>	17.43			
Nd <i>c</i>	17.69			
Ni <i>c</i>	19.4			
Pb <i>c</i>	20.33			
Pr <i>c</i>	17.23			
Sm(III) <i>c</i>	18.63			
Sr <i>c</i>	8.92			
Tb <i>c</i>	19.30			
Tm <i>c</i>	20.46			
VO(II) <i>c</i>	19.40			
Y <i>c</i>	19.41			
Yb <i>c</i>	20.80			
Zn <i>c</i>	18.6			
<b>Dibenzoylmethane (75% dioxane)</b>				
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		
	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_7$ [MHL]
<b>4,5-Dihydroxybenzene-1,3-disulfonic acid (Tiron)</b>				
Al	19.02	31.10	33.5	
Ba	4.10			14.6
Ca	5.80			14.8
Cd <i>d</i>	7.69	13.29		
Ce(III)		3.75		
Co(II) <i>d</i>	8.19	14.41		15.7
Cu(II) <i>d</i>	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) <i>a,c</i>	20.7	35.9	46.9	22.6
La	12.9			18.6 [La(OH)L]
Mg <i>a,c</i>	6.86			14.6
Mn(II) <i>c</i>	8.6			
Ni <i>a,c</i>	8.56	14.90		15.6
Pb <i>d</i>	11.95	18.28		
Sr <i>c</i>	4.55			
UO <sub>2</sub> (II) <i>c</i>	15.90			
VO(II)	15.88			
Zn <i>d</i>	9.00	16.91		15.9
	log $K_1$	log $K_2$	log $K_f$ [M <sub>2</sub> L <sub>3</sub> ]	
<b>2,3-Dimercaptopropan-1-ol (BAL)</b>				
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 $K_4$
<b>Dimethylglyoxime (50% dioxane)</b>				
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		
<b>2,2'-Dipyridyl</b>				
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) <i>d</i>	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	
<b>Eriochrome Black T</b>				
Ca	5.4			
Mg	7.0			
Zn	13.5	20.6		

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

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
<b>Ethanolamine</b>				
Ag	3.29	6.92		16.48
Cu(II)		6.68		
Hg(II)	8.51	17.32		
<b>Ethylenediamine</b>				
Ag	4.70	7.70		
Cd <i>a</i>	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	
<b>Ethylenediamine-<i>N, N, N', N'</i>-tetraacetic acid</b>				
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			
<b>Glycine</b>				
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) <i>a</i>	4.3	7.8		
Fe(III) <i>a,d</i>	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		
<b><i>N'</i>-(2-Hydroxyethyl)ethylenediamine-<i>N,N,N'</i>-triacetic acid</b>				
Ba <i>c</i>	5.54			
Ca <i>c</i>	8.43			
Cd <i>c</i>	13.0			
Ce(III) <i>c</i>	14.11			
Co(II) <i>c</i>	14.4			
Cu(II) <i>c</i>	17.40			
Dy <i>c</i>	15.30			
Er <i>c</i>	15.42			
Eu(III) <i>c</i>	15.35			
Fe(II) <i>c</i>	11.6			
Fe(III) <i>c</i>	19.8			
Gd <i>c</i>	15.22			
Hg(II) <i>c</i>	20.1			
Ho <i>c</i>	15.32			
La <i>c</i>	13.46			
Lu <i>c</i>	15.88			
Mg <i>c</i>	5.78			
Mn(II) <i>c</i>	10.7			
Nd <i>c</i>	14.86			
Ni <i>c</i>	17.0			
Pb <i>c</i>	15.5			
Pr <i>c</i>	14.61			
Sm <i>c</i>	15.28			
Sr <i>c</i>	6.92			
Tb <i>c</i>	15.32			
Th <i>c</i>	18.5			
Tm <i>c</i>	15.59			
Y <i>c</i>	14.65			
Yb <i>c</i>	15.88			
Zn <i>c</i>	14.5			
<b>8-Hydroxy-2-methylquinoline (50% dioxane)</b>				
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 <sub>2</sub> (II)	9.4	17		
Zn	9.82	18.72		
<b>8-Hydroxyquinoline-5-sulfonic acid</b>				
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 <sub>2</sub> (II)	8.52	15.67		
Zn	8.65	16.15		
<b>Lactic acid</b>				
Ba	0.64			
Ca	1.42			
Cd	1.70			
Ce(III) <i>a,c</i>	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 <i>a,c</i>	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 <i>a,c</i>	2.85	4.90	6.10	
Rare earths <i>a,c</i>	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		
<b>Nitrilotriacetic acid</b>				
Al	>10			
Ba <i>a</i>	5.88			
Ca	7.60	11.61		
Cd <i>c</i>	9.80	15.2		
Ce(III) <i>c</i>	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) <i>c</i>	10.38	14.5		
Cr(III)	>10			
Cu(II) <i>c</i>	13.10			
Dy <i>c</i>	11.74	21.15		
Er <i>c</i>	12.03	21.29		
Eu(III) <i>c</i>	11.52	20.70		
Fe(II) <i>c</i>	8.84			
Fe(III) <i>c</i>	15.87	24.32		
Gd <i>c</i>	11.54	20.80		
Hg(II)	12.7			
Ho <i>c</i>	11.90	21.25		
In	15			
La <i>c</i>	10.36	17.60		
Li <i>a</i>	3.28			
Lu <i>c</i>	12.49	21.91		
Mg <i>c</i>	5.36	10.2		
Mn(II)	8.60	11.1		
Na	2.15			
Nd <i>c</i>	11.26	19.73		
Ni	11.26	16.0		
Pb <i>a,c</i>	11.8			
Pr <i>c</i>	11.07	19.25		
Sm(III) <i>c</i>	11.53	20.53		
Sr	6.73			
Tb <i>c</i>	11.59	20.97		
Tl(I)	3.44			
Th <i>c</i>	12.4			
Tm <i>c</i>	12.22	21.45		
Y <i>c</i>	11.48	20.43		
Yb <i>c</i>	12.40	21.69		
Zn <i>c</i>	10.45	13.45		
Zr <i>c</i>	20.8			
<b>1-Nitroso-2-naphthol (75% dioxane)</b>				
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 <i>c</i>	8.50	16.13	24.03	30.29
Y	9.02	17.74	25.04	
Zn	9.32	17.02		
Zr	3.6			
<b>Oxalate</b>				
Ag	2.41			
Al	7.26	13.0	16.3	
Am(III)		9.8		[Am(HL) <sub>4</sub> 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) <i>e</i>	9.98	16.57	19.42	
Mo(III)	3.38			
Mo(VI)				[MoO <sub>3</sub> (L) <sup>2-</sup> 13.0]
Nd	7.21	11.5	> 14	
Ni	5.3	7.64	~8.5	
NpO <sub>2</sub> (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 <sub>2</sub> (II)		11.4		
Sr	2.54			
Th				24.48
TiO(II)	2.67			
Tl(I)	2.03			
UO <sub>2</sub> (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
<b>1,10-Phenanthroline</b>				
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*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
<b>Phthalic acid</b>				
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 <i>d</i>	3.4			
UO <sub>2</sub> (II)	4.38			
Zn	2.2			
<b>Piperidine</b>				
Ag	3.30	6.48		
Hg(II)	8.70	17.44		
Pt(II)			$\log K_5$ 5.7	$\log K_6$ 8.2
<b>Propylene-1,2-diamine</b>				
Cd <i>b,c</i>		9.97	12.12	
Co(II) <i>d</i>	5.42	11.47	14.72	
Cu(II) <i>c</i>	6.41	20.06		
Hg(II) <i>c</i>	10.78	23.53	23.25	
Ni <i>d</i>	7.43	13.62	17.89	
Zn <i>b,c</i>	5.89	10.87	12.57	
<b>Pyridine</b>				
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
Cu(II)	2.59	4.33	5.93	$\log K_6$ 6.89
Fe(II)	0.71		$\log K_5$ 7.00	6.54
Hg(II)	5.1	10.0	10.4	$\log K_6$ 10.2
Mn(II)	1.92	2.77	3.37	3.50
VO(II)	-1.70			
Zn	1.41	1.11	1.61	1.93
<b>Pyridine-2,6-dicarboxylic acid</b>				
Ba <i>a,d</i>	3.46			
Ca <i>a,d</i>	4.6	7.2		
Cd <i>a,d</i>	5.7	10.0		
Ce(III) <i>a,d</i>	8.34	14.42	18.80	
Co(II) <i>a,d</i>	7.0	12.5		
Cu(II) <i>a,d</i>	9.14	16.52		
Dy <i>a,d</i>	8.69	16.19	22.14	
Er <i>a,d</i>	8.77	16.39	22.14	
Eu(III) <i>a,d</i>	8.84	15.98	21.00	
Fe(II) <i>a,d</i>	5.71	10.36		
Fe(III) <i>a,d</i>	10.91	17.13		
Gd <i>a,d</i>	8.74	16.06	21.83	
Ho <i>a,d</i>	8.72	16.23	22.08	
La <i>a,d</i>	7.98	13.79	18.06	
Lu <i>a,d</i>	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) <i>a,d</i>	20.28			
Mg <i>a,d</i>	2.7			
Mn(II) <i>a,d</i>	5.01	8.49		
Nd <i>a,d</i>	8.78	15.60	20.66	
Ni <i>a,d</i>	6.95	13.50		
Pb <i>a,d</i>	8.70	10.60		
Pr <i>a,d</i>	8.63	15.10	19.94	
Sm <i>a,d</i>	8.86	15.88	21.23	
Sr <i>a,d</i>	3.89			
Tb <i>a,d</i>	8.68	16.11	22.03	
Tm <i>a,d</i>	8.83	16.54	22.04	
Y <i>a,d</i>	8.46	15.73	21.34	
Yb <i>a,d</i>	8.85	16.61	21.83	
Zn <i>a,d</i>	6.35	11.88		
<b>1-(2-Pyridylazo)-2-naphthol (PAN)</b>				
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) <sub>2</sub> ]
<b>4-(2-Pyridylazo)resorcinal (PAR)</b>				
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 <sub>2</sub> L]	$\log K_f$ [MHL]
<b>Pyrocatechol-3,5-disulfonate (Pyrocatechol Violet)</b>				
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*)

	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
<b>8-Quinolinol</b>				
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 <sub>2</sub> (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 <sup>+</sup> ]		$\log K_f$ [M(HL) <sub>2</sub> ]	
<b>Salicylaldoxime</b>				
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		
	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$
<b>Salicylic acid</b>				
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) <i>a, c</i>	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 <sub>2</sub> (II)	13.4			
V(II)	6.3			
Zn	6.85			
<b>Succinic acid</b>				
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			
<b>5-Sulfosalicylic acid</b>				
Al <i>c</i>	13.20	22.83	28.89	
Be <i>c</i>	11.71	20.81		
Cd <i>c</i>	16.68	29.08		
Co(II) <i>c</i>	6.13	9.82		
Cr(II) <i>c</i>	7.1	12.9		
Cr(III) <i>c</i>	9.56			
Cu(II) <i>c</i>	9.52	16.45		
Fe(II) <i>c</i>	5.90			
Fe(III) <i>c</i>	14.64	25.18	32.12	
La <i>c</i>	9.11			
Mn(II) <i>c</i>	5.24	8.24		
NbO(III) <i>c</i>	4.0	7.7		
Ni <i>c</i>	6.42	10.24		
UO <sub>2</sub> (II) <i>c</i>	11.14	19.20		
Zn <i>c</i>	6.05	10.65		
<b>Tartaric acid</b>				
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) <sub>2</sub> L <sup>2-</sup> ]

**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) <sub>2</sub> L <sup>2-</sup> ]
Ra	1.24			
Sr	1.60			
Zn	2.68	8.32		
<b>Thioglycolic acid</b>				
Ce(III) <i>a,c</i>	1.99	3.03		
Co(II)	5.84	12.15		
Fe(II)		10.92		
Hg(II)		43.82		
La <i>a,c</i>	1.98	2.98		
Mn(II)	4.38	7.56		
Pb	8.5			
Ni	6.98	13.53		
Rare earths <i>a,c</i>	1.9–2.1	3.0–3.3		
Y <i>a,c</i>	1.91	3.19		
Zn	7.86	15.04		
<b>Thiourea</b>				
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	
<b>Thoron</b>				
Th		10.15		
<b>Triethanolamine</b>				
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			
<b>Triethylenetetramine (Trien)</b>				
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 $K_4$
<b>1,1,1-Trifluoro-3-2'-Thenoylacetone (TTA)</b>				
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 $ZrL^{3+}$ ]			
<b>Xylenol orange</b>				
Bi	5.52			
Fe(III)	5.70			
Hf	6.50			
Tl(III)	4.90			
Zn	6.15			
Zr	7.60			
<b>Zincon</b>				
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)]:

$t, ^\circ\text{C}$ :	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  $\pm 0.03$  pH unit from 25 to 90°C,  $\pm 0.05$  pH unit from 125 to 200°C, and  $\pm 0.1$  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 <sub>2</sub> citrate	0.05 M KH phthalate	0.025 M KH <sub>2</sub> PO <sub>4</sub> , 0.025 M Na <sub>2</sub> HPO <sub>4</sub>	0.0087 M KH <sub>2</sub> PO <sub>4</sub> , 0.0302 M Na <sub>2</sub> HPO <sub>4</sub>	0.01 M Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub>	0.025 M NaHCO <sub>3</sub> , 0.025 M Na <sub>2</sub> CO <sub>3</sub>	Secondary standard Ca(OH) <sub>2</sub> (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 $\Delta\text{pH}_{1/2}$	+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  $\pm 0.003$  in pH in the range 0–50°C, rising to  $\pm 0.02$  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
$\text{KH}_2(\text{C}_2\text{O}_4)_2 \cdot 2\text{H}_2\text{O}$ , 0.05M	12.61
Potassium hydrogen tartrate, about 0.034M	Saturated at 25°C
Potassium hydrogen phthalate, 0.05M	10.12
Phosphate:	
$\text{KH}_2\text{PO}_4$ , 0.025M	3.39
$\text{Na}_2\text{HPO}_4$ , 0.025M	3.53
Phosphate:	
$\text{KH}_2\text{PO}_4$ , 0.008665M	1.179
$\text{Na}_2\text{HPO}_4$ , 0.03032M	4.30
$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ , 0.01M	3.80
Carbonate:	
$\text{NaHCO}_3$ , 0.025M	2.10
$\text{Na}_2\text{CO}_3$ , 0.025M	2.65
$\text{Ca}(\text{OH})_2$ , about 0.0203M	Saturated at 25°C

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

Buffer solution	KH tartrate	0.05 M $\text{KH}_2$ citrate	0.05 M KH phthalate	0.025 M $\text{KH}_2\text{PO}_4$ , 0.25 M $\text{Na}_2\text{HPO}_4$	0.0087 M $\text{KH}_2\text{PO}_4$ , 0.0302 M $\text{Na}_2\text{HPO}_4$	0.01 M $\text{Na}_2\text{B}_4\text{O}_7$	0.025 M $\text{NaHCO}_3$ , 0.025 M $\text{Na}_2\text{CO}_3$
Buffer value $\beta$	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 dioxide 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 ( $\text{pH}_s = 6.480$  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  $\text{KH}_2\text{PO}_4$  and 5.677 g of  $\text{Na}_2\text{HPO}_4$  (air weights) in carbon dioxide-free water to make 1 liter of solution. The  $\text{pH}_s$  is  $7.416 \pm 0.004$  at 37.5 and 38°C.

The compositions and  $\text{pH}_s$  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  $\beta$ .

25 ml 0.2M KCl + $x$ ml 0.2M HCl, Diluted to 100 ml			50 ml 0.1M KH Phthalate + $x$ ml 0.1M HCl, Diluted to 100 ml			50 ml 0.1M KH Phthalate + $x$ ml 0.1M NaOH, Diluted to 100 ml		
pH	$x$	$\beta$	pH	$x$	$\beta$	pH	$x$	$\beta$
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 0.1M KH <sub>2</sub> PO <sub>4</sub> + $x$ ml 0.1M NaOH, Diluted to 100 ml			50 ml 0.1M Tris(hydroxy- methyl)aminomethane + $x$ ml 0.1M HCl, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.028$ $I = 0.001x$			50 ml of a Mixture 0.1M with Respect to Both KCl and H <sub>3</sub> B <sub>3</sub> O <sub>3</sub> + $x$ ml 0.1M NaOH, Diluted to 100 ml		
pH	$x$	$\beta$	pH	$x$	$\beta$	pH	$x$	$\beta$
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 0.025M Borax + $x$ ml 0.1M HCl, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.008$ $I = 0.025$			50 ml 0.025M Borax + $x$ ml 0.1M NaOH, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.008$ $I = 0.001(25 + x)$			50 ml 0.05M NaHCO <sub>3</sub> + $x$ ml 0.1M NaOH, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.009$ $I = 0.001(25 + 2x)$		
pH	$x$	$\beta$	pH	$x$	$\beta$	pH	$x$	$\beta$
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 0.025M Borax + $x$ ml 0.1M HCl, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.008$ $I = 0.025$			50 ml 0.025M Borax + $x$ ml 0.1M NaOH, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.008$ $I = 0.001(25 + x)$			50 ml 0.05M NaHCO <sub>3</sub> + $x$ ml 0.1M NaOH, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.009$ $I = 0.001(25 + 2x)$			
pH	$x$	$\beta$	pH	$x$	$\beta$	pH	$x$	$\beta$	
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 0.05M Na <sub>2</sub> HPO <sub>4</sub> + $x$ ml 0.1M NaOH, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.025$ $I = 0.001(77 + 2x)$					25 ml 0.2M KCl + $x$ ml 0.2M NaOH, Diluted to 100 ml $\Delta\text{pH}/\Delta t \approx -0.033$ $I = 0.001(50 + 2x)$				
pH	$x$	$\beta$	pH	$x$	$\beta$	pH	$x$	$\beta$	
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  $\text{pH}_s$ , shown below:

Molality $\text{KH}_2\text{PO}_4$ = Molality $\text{Na}_2\text{HC}_6\text{H}_5\text{O}_7$	$\text{pH}_s$	$\Delta(\text{pH}_s/\Delta t)$
0.005	6.251	$-0.000\ 86\ \text{deg}^{-1}$
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  $\text{pH}_s^*$  for the Measurement of Acidity in 50 Weight Percent Methanol-Water

Temperature, °C	0.02 <i>m</i> HOAc, 0.02 <i>m</i> NaOAc, 0.02 <i>m</i> NaCl	0.02 <i>m</i> NaHSuc, 0.02 <i>m</i> NaCl	0.02 <i>m</i> $\text{KH}_2\text{PO}_4$ , 0.02 <i>m</i> $\text{Na}_2\text{HPO}_4$ , 0.02 <i>m</i> 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**  $\text{pH}^*$  Values for Buffer Solutions in Alcohol-Water Solvents at 25°C*Liquid-junction potential not included.*

Solvent Composition (weight per cent alcohol)	0.01 <i>M</i> $\text{H}_2\text{C}_2\text{O}_4$ , 0.01 <i>M</i> $\text{NH}_4\text{HC}_2\text{O}_4$	0.01 <i>M</i> $\text{H}_2\text{Suc}$ , 0.01 <i>M</i> $\text{LiHSuc}$	0.01 <i>M</i> $\text{HSal}$ , 0.01 <i>M</i> $\text{NaSal}$
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
<i>p</i> -Toluenesulfonate and <i>p</i> -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-( <i>N</i> -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 <sub>2</sub> PO <sub>4</sub> and borax		2.2, 7.2; 9	5.8–9.2
<i>N</i> -(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- <i>N,N'</i> -bis(2-ethanesulfonic acid)	PIPES	6.8	6.1–7.5
3-( <i>N</i> -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 <sub>2</sub> PO <sub>4</sub> and Na <sub>2</sub> HPO <sub>4</sub>		7.2	6.1–7.5
<i>N,N</i> -Bis(2-hydroxyethyl)-2-aminoethanesulfonic acid	BES	7.1	6.4–7.8
3-( <i>N</i> -Morpholino)propanesulfonic acid	MOPS	7.2	6.5–7.9
<i>N</i> -(2-Hydroxyethyl)piperazine- <i>N'</i> -(2-ethanesulfonic acid)	HEPES	7.5	6.8–8.2
<i>N</i> -Tris(hydroxymethyl)methyl-2-aminoethanesulfonic acid	TES	7.5	6.8–8.2
3-[ <i>N,N</i> -Bis(2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid	DIPSO	7.6	7.0–8.2
3-[ <i>N</i> -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
<i>N</i> -(2-hydroxyethyl)piperazine- <i>N'</i> -(2-hydroxypropanesulfonic acid)	HEPPSO	7.8	7.1–8.5
Piperazine- <i>N,N'</i> -bis(2-hydroxypropanesulfonic acid)	POPSO	7.8	7.2–8.5
Triethanolamine	TEA	7.8	6.9–8.5
<i>N</i> -Tris(hydroxymethyl)methylglycine	TRICINE	8.1	7.4–8.8
Borax and HCl			7.6–8.9
<i>N,N</i> -Bis(2-hydroxyethyl)glycine	BICINE	8.3	7.6–9.0
<i>N</i> -Tris(hydroxymethyl)methyl-3-aminopropanesulfonic acid	TAPS	8.4	7.7–9.1
3-[(1,1-Dimethyl-2-hydroxyethyl)-2-hydroxypropanesulfonic acid	AMPPO	9.0	8.3–9.7
Ammonia (aqueous) and NH <sub>4</sub> Cl		9.2	8.3–9.2
2-( <i>N</i> -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 <sub>2</sub> HPO <sub>4</sub> and NaOH				11.9	11.0–12.0

x mL of 0.2M Sodium Acetate (27.199 g NaOAc · 3H <sub>2</sub> O per liter) plus y mL of 0.2M Acetic Acid			x mL of 0.1M KH <sub>2</sub> PO <sub>4</sub> (13.617 g · L <sup>-1</sup> ) plus y mL of 0.05M Borax Solution (19.404 g Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> · 10H <sub>2</sub> O per Liter)					
pH	NaOAc, mL	Acetic Acid, mL	pH	KH <sub>2</sub> PO <sub>4</sub> , mL	Borax, mL	pH	KH <sub>2</sub> PO <sub>4</sub> , mL	Borax, mL
3.60	7.5	92.5	5.80	92.1	7.9	7.60	51.7	48.3
3.80	12.0	88.0	6.00	87.7	12.3	7.80	49.2	50.8
4.00	18.0	82.0	6.200	83.0	17.0	8.00	46.5	53.5
4.20	26.5	73.5	6.40	77.8	22.2	8.20	43.0	57.0
4.40	37.0	63.0	6.60	72.2	27.8	8.40	38.7	61.3
4.60	49.0	51.0	6.80	66.7	33.3	8.60	34.0	66.0
4.80	60.0	40.0	7.00	62.3	37.7	8.80	27.6	72.4
5.00	70.5	29.5	7.20	58.1	41.9	9.00	17.5	82.5
5.20	79.0	21.0	7.40	55.0	45.0	9.20	5.0	95.0
5.40	85.5	14.5						
5.60	90.5	9.5						

x mL of Veronal (20.6 g Na Diethylbarbiturate per Liter) plus y mL of 0.1M HCl			x mL of 0.2M Aqueous NH <sub>3</sub> Solution plus y mL of 0.2M NH <sub>4</sub> Cl (10.699 g · L <sup>-1</sup> )			x mL of 0.1M Citrate (21.0 g Citric Acid Monohydrate + 200 mL 1M NaOH per Liter) plus y mL of 0.1M NaOH		
pH	Veronal, mL	HCl, mL	pH	Aq NH <sub>3</sub> , mL	NH <sub>4</sub> Cl, mL	pH	Citrate, mL	NaOH, mL
7.00	53.6	46.4	8.00	5.5	94.5	5.10	90.0	10.0
7.20	55.4	44.6	8.20	8.5	91.5	5.30	80.0	20.0
7.40	58.1	41.9	8.40	12.5	87.5	5.50	71.0	29.0
7.60	61.5	38.5	8.60	18.5	81.5	5.70	67.0	33.0
7.80	66.2	33.8	8.80	26.0	74.0	5.90	62.0	38.0
8.00	71.6	28.4	9.00	36.0	64.0			
8.20	76.9	23.1	9.25	50.0	50.0			
8.40	82.3	17.7	9.40	58.5	41.5			
8.60	87.1	12.9	9.60	69.0	31.0			
8.80	90.8	9.2	9.80	78.0	22.0			
9.00	93.6	6.4	10.00	85.0	15.0			

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

<i>x</i> mL of 0.2M NaOH Added to 100 mL of Stock Solution (0.04M Acetic Acid, 0.04M H <sub>3</sub> PO <sub>4</sub> , and 0.04M Boric Acid)								
pH	NaOH, mL		pH	NaOH, mL		pH	NaOH, mL	
1.81	0.0		4.10	25.0		6.80	50.0	
1.89	2.5		4.35	27.5		7.00	52.5	
1.98	5.0		4.56	30.0		7.24	55.0	
2.09	7.5		4.78	32.5		7.54	57.5	
2.21	10.0		5.02	35.0		7.96	60.0	
2.36	12.5		5.33	37.5		8.36	62.5	
2.56	15.0		5.72	40.0		8.69	65.0	
2.87	17.5		6.09	42.5		8.95	67.5	
3.29	20.0		6.37	45.0		9.15	70.0	
3.78	22.5		6.59	47.5		9.37	72.5	
<i>x</i> mL of 0.1M HCl plus <i>y</i> mL of 0.1M Glycine (7.505 g Glycine + 5.85 g NaCl per Liter)			<i>x</i> mL of 0.1M HCl plus <i>y</i> mL of 0.1M Citrate (21.008 g Citric Acid Monohydrate + 200 ml 1M NaOH per Liter)			<i>x</i> mL of 0.05M Succinic Acid (5.90 g · L <sup>-1</sup> ) plus <i>y</i> mL of Borax Solution (19.404 g Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> · 10H <sub>2</sub> O 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
<i>x</i> mL of 0.2M Na <sub>2</sub> HPO <sub>4</sub> · 2H <sub>2</sub> O (35.599 g · L <sup>-1</sup> ) plus <i>y</i> mL of 0.1M Citric Acid (19.213 g · L <sup>-1</sup> )								
pH	Na <sub>2</sub> HPO <sub>4</sub> , mL	Citric Acid, mL	pH	Na <sub>2</sub> HPO <sub>4</sub> , mL	Citric Acid, mL	pH	Na <sub>2</sub> HPO <sub>4</sub> , 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  $\text{Na}_2\text{HPO}_4$  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  $\text{Na}_2\text{CO}_3$ ,  $\text{NaH}_2\text{PO}_4$ , 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	0.1M KCl Calomel*	1.0M KCl Calomel*	3.5M KCl Calomel*	Satd. KCl Calomel*	1.0M KCl Ag/AgCl†	1.0M KBr Ag/AgBr‡	1.0M 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
1.0M KCl Ag/AgCl*	0.1330	0.1032	0.0708	0.0348	-0.0051	-0.054	-0.090
1.0M 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, 0.1M KCl	0.288
Hg/HgO, 1.0M NaOH	0.140
Hg/HgO, 0.1M NaOH	0.165
Hg/Hg <sub>2</sub> SO <sub>4</sub> , satd. K <sub>2</sub> SO <sub>4</sub> (22°C)	0.658
Hg/Hg <sub>2</sub> SO <sub>4</sub> , satd. KCl	0.655

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

$$\text{pH}_x = \text{pH}_s + \frac{E_x - E_s}{2.3026RT/F}$$

where  $R$  is the gas constant per mole,  $T$  is the temperature on the absolute scale, and  $F$  is the faraday. The  $\text{pH}_x$  of the unknown medium is calculated from that of an accepted standard ( $\text{pH}_s$ ) 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. 3.5M or saturated)	Reference electrode
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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		

## 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	$pK_a$	$\lambda_{\max}$ , nm	Color change
Cresol red (acid range)	<i>o</i> -Cresolsulfonephthalein	0.2–1.8			R-Y
Cresol purple (acid range)	<i>m</i> -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- <i>p</i> -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- <i>m</i> -cresolsulfonephthalein	4.0–5.6	4.68	444, 617	Y-B
Methyl red	<i>o</i> -Carboxybenzeneazo-dimethylaniline	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- <i>o</i> -cresolsulfonephthalein	5.2–6.8	6.3	433, 591	Y-P
Bromophenol red	Dibromophenolsulfonephthalein	5.2–6.8		—, 574	Y-R
<i>p</i> -Nitrophenol	<i>p</i> -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	Aminodimethylaminotoluenazonium chloride	6.8–8.0	7.4		R-Y
Phenol red	Phenolsulfonephthalein	6.4–8.0	7.9	433, 558	Y-R
<i>m</i> -Nitrophenol	<i>m</i> -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	$pK_a$	$\lambda_{\max}$ , nm	Color change
Cresol red	<i>o</i> -Cresolsulfonephthalein	7.2–8.8	8.2	434, 572	Y-R
<i>m</i> -Cresol purple	<i>m</i> -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
$\alpha$ -Naphtholbenzein	$\alpha$ -Naphtholbenzein	9.0–11.0			Y-B
Thymolphthalein	Thymolphthalein	9.4–10.6	10.0	—, 598	C-B
Alizarin Yellow R	5-( <i>p</i> -Nitrophenylazo)-salicylic acid, Na salt	10.0–12.0	11.16		Y-V
Tropeolin O	<i>p</i> -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 ( $pI$ ).

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	$pI$	Color		Notes
		Acid	Alkaline	
1 part 0.1% methyl yellow in alc. 1 part 0.1% methylene blue in alc.	*	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.	*	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.	*	Violet	Green	Good indicator, especially in artificial light
1 part 0.1% methyl orange in aq. 1 part 0.1% aniline blue in aq.		Violet	Green	
1 part 0.1% bromcresol green sodium salt in aq. 1 part 0.02% methyl orange in aq.		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.		Wine-red	Green	Very sharp color change†
1 part 0.2% methyl red in alc. 1 part 0.1% methylene blue in alc.	*	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		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.		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.		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.		Violet	Blue	

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

\* 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 in 50% ethanol)
	4.0 to 6.0	Green to blue	
	11.6 to 13.0	Blue to non-fl	
1-Naphthylamino-6-sulfonamide (also the 1-, 7-)	1.9 to 3.9	Non-fl to green	3
	9.6 to 13.0	Green to non-fl	
2-Naphthylamino-6-sulfonamide (also the 2-, 8-)	1.9 to 3.9	Non-fl to dark blue	3
	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 (tetrachlorotetrabromofluorescein)	2.5 to 4.0	Non-fl to dark blue	2
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	
<i>p</i> -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	
<i>o</i> -Methoxybenzaldehyde	3.1 to 4.4	Non-fl to green	4 (0.2%)
<i>o</i> -Phenylenediamine	3.1 to 4.4	Green to non-fl	5
<i>p</i> -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
$\beta$ -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)
$\beta$ -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-hydroxyquinolate	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
$\beta$ -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
<i>o</i> -Hydroxyphenylbenzothiazole	9.3	Non-fl to blue green	2
<i>o</i> -Hydroxyphenylbenzoxazole	9.3	Non-fl to blue/violet	2
<i>o</i> -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		Suitable pH Range	Color Change Upon Oxidation
	pH = 0	pH = 7		
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 <sub>2</sub> SO <sub>4</sub> )* 0.87 (1.0 M H <sub>2</sub> SO <sub>4</sub> )*			Red to faint blue
<i>o,m'</i> -Diphenylaminedicarboxylic acid	1.12			Colorless to blue-violet
Setopaline	1.06 ( <i>trans</i> )†			Yellow to orange
<i>p</i> -Nitrodiphenylamine	1.06			Colorless to violet
Tris(1,10-phenanthroline)-iron(II) sulfate	1.06 (1.00 M H <sub>2</sub> SO <sub>4</sub> )* 1.00 (3.0 M H <sub>2</sub> SO <sub>4</sub> )* 0.89 (6.0 M H <sub>2</sub> SO <sub>4</sub> )*			Red to faint blue
Setoglaucine O	1.01 ( <i>trans</i> )†			Yellow-green to yellow-red
Xylene cyanole FF	1.00 ( <i>trans</i> )†			Yellow-green to pink
Erioglaucine A	1.00 ( <i>trans</i> )†			Green-yellow to bluish red
Eriogreen	0.99 ( <i>trans</i> )†			Green-yellow to orange
Tris(2,2'-bipyridine)-iron(II) hydrochloride	0.97*			Red to faint blue
2-Carboxydiphenylamine [ <i>N</i> -phenyl- anthranilic acid]	0.94			Colorless to pink
Benzidine dihydrochloride	0.92			Colorless to blue
<i>o</i> -Toluidine	0.87			Colorless to blue
Bis(1,10-phenanthroline)-osmium(II) perchlorate	0.859 (0.1 M H <sub>2</sub> SO <sub>4</sub> )			Green to pink
Diphenylamine-4-sulfonate (Na salt)	0.85			Colorless to violet

3,3'-Dimethoxybenzidine dihydrochloride [ <i>o</i> -dianisidine]	0.85			Colorless to red
Ferrocypen	0.81			Yellow to violet
4'-Ethoxy-2,4-diaminoazobenzene	0.76			Red to pale yellow
<i>N,N</i> -Diphenylbenzidine	0.76			Colorless to violet
Diphenylamine	0.76			Colorless to violet
<i>N,N</i> -Dimethyl- <i>p</i> -phenylenediamine	0.76			Colorless to red
Variamine blue B hydrochloride	0.712‡	0.310	1.5–6.3	Colorless to blue
<i>N</i> -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-methylphenoxyazaine 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 <sub>3</sub> <sup>-</sup> 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
Phenosafranin	0.280‡	–0.252	1–11	Colorless to violet-blue
Indigo-5-monosulfonic acid (Na salt)	0.262‡	–0.157	<9	Colorless to blue
Safranin T	0.24‡	–0.289	1–12	Colorless to violet-blue
Bis(dimethylglyoximate)-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  $E^\circ$

‡ Values of  $E^\circ$  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
<b>Actinium</b>		
$\text{Ac}^{3+} + 3e^- = \text{Ac}$	-2.13	
<b>Aluminum</b>		
$\text{Al}^{3+} + 3e^- = \text{Al}$	-1.676	
$\text{AlF}_6^{3-} + 3e^- = \text{Al} + 6\text{F}^-$	-2.07	
$\text{Al}(\text{OH})_4^- + 3e^- = \text{Al} + 4\text{OH}^-$	-2.310	
<b>Americium</b>		
$\text{AmO}_2^{2+} + 4\text{H}^+ + 2e^- = \text{Am}^{4+} + 2\text{H}_2\text{O}$	1.20	
$\text{AmO}_2^{2+} + e^- = \text{AmO}_2^+$	1.59	
$\text{AmO}_2^+ + 4\text{H}^+ + e^- = \text{Am}^{4+} + 2\text{H}_2\text{O}$	0.82	
$\text{AmO}_2^+ + 4\text{H}^+ + 2e^- = \text{Am}^{3+} + 2\text{H}_2\text{O}$	1.72	
$\text{Am}^{4+} + e^- = \text{Am}^{3+}$	2.62	
$\text{Am}^{4+} + 4e^- = \text{Am}$	-0.90	
$\text{Am}^{3+} + 3e^- = \text{Am}$	-2.07	
<b>Antimony</b>		
$\text{Sb}(\text{OH})_4^- + 2e^- = \text{SbO}_2 + 2\text{OH}^- + 2\text{H}_2\text{O}$	-0.465	1 NaOH
$\text{SbO}_2 + 2\text{H}_2\text{O} + 3e^- = \text{Sb} + 4\text{OH}^-$	0.639	1 NaOH
$\text{Sb} + 3\text{H}_2\text{O} + 3e^- = \text{SbH}_3 + 3\text{OH}^-$	-1.338	1 NaOH
$\text{Sb}_2\text{O}_5 + 6\text{H}^+ + 4e^- = 2\text{SbO}^+ + 3\text{H}_2\text{O}$	0.605	
$\text{Sb}_2\text{O}_5 + 4\text{H}^+ + 4e^- = \text{Sb}_2\text{O}_3 + 2\text{H}_2\text{O}$	0.699	
$\text{Sb}_2\text{O}_5 + 2\text{H}^+ + 2e^- = \text{Sb}_2\text{O}_4 + \text{H}_2\text{O}$	1.055	
$\text{Sb}_2\text{O}_4 + 2\text{H}^+ + 2e^- = \text{Sb}_2\text{O}_3 + \text{H}_2$	0.342	
$\text{SbO}^+ + 2\text{H}^+ + 3e^- = \text{Sb} + \text{H}_2\text{O}$	0.204	
$\text{Sb} + 3\text{H}^+ + 3e^- = \text{SbH}_3$	-0.510	
<b>Arsenic</b>		
$\text{H}_3\text{AsO}_4 + 2\text{H}^+ + 2e^- = \text{HAsO}_2 + 2\text{H}_2\text{O}$	0.560	
$\text{HAsO}_2 + 3\text{H}^+ + 3e^- = \text{As} + 2\text{H}_2\text{O}$	0.240	
$\text{As} + 3\text{H}^+ + 3e^- = \text{AsH}_3$	-0.225	
$\text{AsO}_4^{3-} + 2\text{H}^+ + 2e^- = \text{AsO}_2^- + 4\text{OH}^-$	-0.67	
$\text{AsO}_2^- + 2\text{H}_2\text{O} + 3e^- = \text{As} + 4\text{OH}^-$	-0.68	
$\text{As} + 3\text{H}_2\text{O} + 3e^- = \text{AsH}_3 + 3\text{OH}^-$	-1.37	
<b>Astatine</b>		
$\text{HAtO}_3 + 4\text{H}^+ + 4e^- = \text{HAtO} + 2\text{H}_2$	ca. 1.4	
$2\text{HAtO} + 2\text{H}^+ + 2e^- = \text{At}_2 + 2\text{H}_2\text{O}$	ca. 0.7	
$\text{At}_2 + 2e^- = 2\text{At}^-$	0.20	
<b>Barium</b>		
$\text{BaO}_2 + 4\text{H}^+ + 2e^- = \text{Ba}^{2+} + 2\text{H}_2\text{O}$	2.365	
$\text{Ba}^{2+} + 2e^- = \text{Ba}$	-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
<b>Berkelium</b>		
$\text{Bk}^{4+} + 4e^- = \text{Bk}$	-1.05	
$\text{Bk}^{4+} + e^- = \text{Bk}^{3+}$	1.67	
$\text{Bk}^{3+} + 3e^- = \text{Bk}$	-2.01	
<b>Beryllium</b>		
$\text{Be}^{2+} + 2e^- = \text{Be}$	-1.99	
<b>Bismuth</b>		
$\text{Bi}_2\text{O}_4$ (bismuthate) + $4\text{H}^+ + 2e^- = 2\text{BiO}^+ + 2\text{H}_2\text{O}$	1.59	
$\text{Bi}^{3+} + 3e^- = \text{Bi}$	0.317	
$\text{Bi} + 3\text{H}^+ + 3e^- = \text{BiH}_3$	-0.97	
$\text{BiCl}_4^- + 3e^- = \text{Bi} + 4\text{Cl}^-$	0.199	
$\text{BiBr}_4^- + 3e^- = \text{Bi} + 4\text{Br}^-$	0.168	
$\text{BiOCl} + 2\text{H}^+ + 3e^- = \text{Bi} + \text{H}_2\text{O} + \text{Cl}^-$	0.170	
<b>Boron</b>		
$\text{B}(\text{OH})_3 + 3\text{H}^+ + 3e^- = \text{B} + 3\text{H}_2\text{O}$	-0.890	
$\text{BO}_2^- + 6\text{H}_2\text{O} + 8e^- = \text{BH}_3^- + 8\text{OH}^-$	-1.241	
$\text{B}(\text{OH})_4^- + 3e^- = \text{B} + 4\text{OH}^-$	-1.811	
<b>Bromine</b>		
$\text{BrO}_4^- + 2\text{H}^+ + 2e^- = \text{BrO}_3^- + \text{H}_2\text{O}$	1.853	
$\text{BrO}_3^- + 6\text{H}^+ + 6e^- = \text{Br}^- + 3\text{H}_2\text{O}$	1.478	
$\text{BrO}_3^- + 5\text{H}^+ + 4e^- = \text{HBrO} + 2\text{H}_2\text{O}$	1.444	
$2\text{BrO}_3^- + 12\text{H}^+ + 10e^- = \text{Br}_2 + 6\text{H}_2\text{O}$	1.5	
$2\text{HBrO} + 2\text{H}^+ + 2e^- = \text{Br}_2 + 2\text{H}_2\text{O}$	1.604	
$\text{HBrO} + \text{H}^+ + 2e^- = \text{Br}^- + \text{H}_2\text{O}$	1.341	
$\text{BrO}^- + \text{H}_2\text{O} + 2e^- = \text{Br}^- + 2\text{OH}^-$	0.76	1 NaOH
$\text{Br}_3^- + 2e^- = 3\text{Br}^-$	1.050	
$\text{Br}_2(\text{aq}) + 2e^- = 2\text{Br}^-$	1.087	
<b>Cadmium</b>		
$\text{Cd}^{2+} + 2e^- = \text{Cd}$	-0.403	
$\text{Cd}^{2+} + \text{Hg} + 2e^- = \text{Cd}(\text{Hg})$	-0.352	
$\text{CdCl}_3^- + 2e^- = \text{Cd} + 4\text{Cl}^-$	-0.453	
$\text{Cd}(\text{CN})_4^{2-} + 2e^- = \text{Cd} + 4\text{CN}^-$	-0.943	
$\text{Cd}(\text{NH}_3)_4^{2+} + 2e^- = \text{Cd} + 4\text{NH}_3$	-0.622	
$\text{Cd}(\text{OH})_4^{2-} + 2e^- = \text{Cd} + 4\text{OH}^-$	-0.670	
<b>Calcium</b>		
$\text{CaO}_2 + 4\text{H}^+ + 2e^- = \text{Ca}^{2+} + \text{H}_2\text{O}$	2.224	
$\text{Ca}^{2+} + 2e^- = \text{Ca}$	-2.84	
$\text{Ca} + 2\text{H}^+ + 2e^- = \text{CaH}_2$	0.776	
<b>Californium</b>		
$\text{Cf}^{3+} + 3e^- = \text{Cf}$	-1.93	
$\text{Cf}^{3+} + e^- = \text{Cf}^{2+}$	-1.6	
$\text{Cf}^{2+} + 2e^- = \text{Cf}$	-2.1	
<b>Carbon</b>		
$\text{CO}_2 + 2\text{H}^+ + 2e^- = \text{CO} + \text{H}_2\text{O}$	-0.106	
$\text{CO}_2 + 2\text{H}^+ + 2e^- = \text{HCOOH}$	-0.20	
$2\text{CO}_2 + 2\text{H}^+ + 2e^- = \text{H}_2\text{C}_2\text{O}_4$	-0.481	
$\text{C}_2\text{O}_4^{2-} + 2\text{H}^+ + 2e^- = 2\text{HCOO}^-$	0.145	
$\text{HCOOH} + 2\text{H}^+ + 2e^- = \text{HCHO} + \text{H}_2\text{O}$	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	
<b>Cerium</b>		
$Ce(IV) + e^- = Ce(III)$	1.70	1 HClO <sub>4</sub>
	1.61	1 HNO <sub>3</sub>
	1.44	0.5 H <sub>2</sub> SO <sub>4</sub>
	1.28	1 HCl
$Ce^{3+} + 3e^- = Ce$	-2.34	
<b>Cesium</b>		
$Cs^+ + e^- = Cs$	-2.923	
$Cs^+ + Hg + e^- = Cs(Hg)$	-1.78	
<b>Chlorine</b>		
$ClO_4^- + 2H^+ + 2e^- = ClO_3^- + H_2O$	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	
<b>Chromium</b>		
$Cr_2O_7^{2-} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$	1.36	
	1.15	0.1 H <sub>2</sub> SO <sub>4</sub>
	1.03	1 HClO <sub>4</sub>
$CrO_4^{2-} + 4H_2O + 3e^- = Cr(OH)_4^- + 4OH^-$	-0.13	1 NaOH
$Cr^{3+} + e^- = Cr^{2+}$	-0.424	
$Cr^{3+} + 3e^- = Cr$	-0.74	
$Cr^{2+} + 2e^- = Cr$	0.90	
<b>Cobalt</b>		
$CoO_2 + 4H^+ + e^- = Co^{3+} + 2H_2O$	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 <sub>3</sub>
$Co(OH)_3 + e^- = Co(OH)_2 + OH^-$	0.17	
$Co(en)_3^{3+} + e^- = Co(en)_3^{2+}$ [en = ethylenediamine]	-0.2	0.1 en
$Co(CN)_6^{3-} + e^- = Co(CN)_6^{2-} + CN^-$	-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
<b>Copper</b>		
$\text{Cu}^{2+} + 2e^- = \text{Cu}$	0.340	
$\text{Cu}^{2+} + e^- = \text{Cu}^+$	0.159	
$\text{Cu}^+ + e^- = \text{Cu}$	0.520	
$\text{Cu}^{2+} + \text{Cl}^- + e^- = \text{CuCl}$	0.559	
$\text{Cu}^{2+} + 2\text{Br}^- + e^- = \text{CuBr}_2^-$	0.52	1 KBr
$\text{Cu}^{2+} + \text{I}^- + e^- + \text{CuI}$	0.86	
$\text{Cu}^{2+} + 2\text{CN}^- + e^- = \text{Cu}(\text{CN})_2^-$	1.12	
$\text{Cu}(\text{NH}_3)_4^{2+} + e^- = \text{Cu}(\text{NH}_3)_2^+ + 2\text{NH}_3$	0.10	1 $\text{NH}_3$
$\text{Cu}(\text{en})_2^{2+} + e^- = \text{Cu}(\text{en})^+ + \text{en}$	-0.35	
$\text{Cu}(\text{CN})_2^- + e^- = \text{Cu} + 2\text{CN}^-$	-0.44	
$\text{CuCl}_2 + e^- = \text{Cu} + 2\text{Cl}^-$	0.178	1 HCl
$\text{Cu}(\text{NH}_3)_2^+ + e^- = \text{Cu} + 2\text{NH}_3$	-0.100	
<b>Curium</b>		
$\text{Cm}^{4+} + e^- = \text{Cm}^{3+}$	3.2	1 $\text{HClO}_4$
$\text{Cm}^{3+} + 3e^- = \text{Cm}$	-2.06	
<b>Dysprosium</b>		
$\text{Dy}^{3+} + 3e^- = \text{Dy}$	-2.29	
$\text{Dy}^{3+} + e^- = \text{Dy}^{2+}$	-2.5	
$\text{Dy}^{2+} + 2e^- = \text{Dy}$	-2.2	
<b>Einsteinium</b>		
$\text{Es}^{3+} + 3e^- = \text{Es}$	-2.0	
$\text{Es}^{3+} + e^- = \text{Es}^{2+}$	-1.5	
$\text{Es}^{2+} + 2e^- = \text{Es}$	-2.2	
<b>Erbium</b>		
$\text{Er}^{3+} + 3e^- = \text{Er}$	-2.32	
<b>Europium</b>		
$\text{Eu}^{3+} + 3e^- = \text{Eu}$	-1.99	
$\text{Eu}^{3+} + e^- = \text{Eu}^{2+}$	-0.35	
$\text{Eu}^{2+} + 2e^- = \text{Eu}$	-2.80	
<b>Fermium</b>		
$\text{Fm}^{3+} + 3e^- = \text{Fm}$	-1.96	
$\text{Fm}^{3+} + e^- = \text{Fm}^{2+}$	-1.15	
$\text{Fm}^{2+} + 2e^- = \text{Fm}$	-2.37	
<b>Fluorine</b>		
$\text{F}_2 + 2\text{H}^+ + 2e^- = 2\text{HF}$	3.053	
$\text{F}_2 + \text{H}^+ + 2e^- = \text{HF}_2^-$	2.979	
$\text{F}_2 + 2e^- = 2\text{F}^-$	2.87	
$\text{OF}_2 + 3\text{H}^+ + 4e^- = \text{HF}_2^- + \text{H}_2\text{O}$	2.209	
<b>Francium</b>		
$\text{Fr}^+ + e^- = \text{Fr}$	ca. -2.9	
<b>Gadolinium</b>		
$\text{Gd}^{3+} + 3e^- = \text{Gd}$	-2.28	
<b>Gallium</b>		
$\text{Ga}^{3+} + 3e^- = \text{Ga}$	-0.529	
$\text{Ga}^{3+} + e^- = \text{Ga}^{2+}$	-0.65	
$\text{Ga}^{2+} + 2e^- = \text{Ga}$	-0.45	

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

Half-reaction	Standard or formal potential	Solution composition
<b>Germanium</b>		
$\text{GeO}_2(\text{tetr}) + 2\text{H}^+ + 2e^- = \text{GeO}(\text{yellow}) + \text{H}_2\text{O}$	-0.255	
$\text{GeO}_2(\text{tetr}) + 4\text{H}^+ + 2e^- = \text{Ge}^{2+} + 2\text{H}_2\text{O}$	-0.210	
$\text{GeO}_2(\text{hex}) + 4\text{H}^+ + 2e^- = \text{Ge}^{2+} + 2\text{H}_2\text{O}$	-0.132	
$\text{H}_2\text{GeO}_3 + 4\text{H}^+ + 4e^- = \text{Ge} + 3\text{H}_2\text{O}$	0.012	
$\text{Ge}^{4+} + 2e^- = \text{Ge}^{2+}$	0.0	
$\text{Ge}^{2+} + 2e^- = \text{Ge}$	0.247	
$\text{GeO} + 2\text{H}^+ + 2e^- = \text{Ge} + \text{H}_2\text{O}$	-0.255	
$\text{Ge} + 4\text{H}^+ + 4e^- = \text{GeH}_4$	-0.29	
<b>Gold</b>		
$\text{Au}^{3+} + 3e^- = \text{Au}$	1.52	
$\text{Au}^{3+} + 2e^- = \text{Au}^+$	1.36	
$\text{Au}^+ + e^- = \text{Au}$	1.83	
$\text{AuCl}_4^- + 2e^- = \text{AuCl}_2^- + 2\text{Cl}^-$	0.926	
$\text{AuBr}_4^- + 2e^- = \text{AuBr}_2^- + 2\text{Br}^-$	0.802	
$\text{Au}(\text{SCN})_4^- + 2e^- = \text{Au}(\text{SCN})_2^- + 2\text{SCN}^-$	0.623	
$\text{AuBr}_4^- + 3e^- = \text{Au} + 4\text{Br}^-$	0.854	
$\text{AuCl}_4^- + 3e^- = \text{Au} + 4\text{Cl}^-$	1.002	
$\text{Au}(\text{SCN})_4^- + 3e^- = \text{Au} + 4\text{SCN}^-$	0.662	
$\text{Au}(\text{OH})_3 + 3\text{H}^+ + 3e^- = \text{Au} + 3\text{H}_2\text{O}$	1.45	
$\text{AuBr}_2^- + e^- = \text{Au} + 2\text{Br}^-$	0.960	
$\text{AuCl}_2^- + e^- = \text{Au} + 2\text{Cl}^-$	1.15	
$\text{AuI}_2^- + e^- = \text{Au} + 2\text{I}^-$	0.576	
$\text{Au}(\text{CN})_2^- + e^- = \text{Au} + 2\text{CN}^-$	-0.596	
$\text{Au}(\text{SCN})_2 + e^- = \text{Au} + 2\text{SCN}^-$	0.69	
<b>Hafnium</b>		
$\text{Hf}^{4+} + 4e^- = \text{Hf}$	-1.70	
$\text{HfO}_2 + 4\text{H}^+ + 4e^- = \text{Hf} + 2\text{H}_2\text{O}$	-1.57	
<b>Holmium</b>		
$\text{Ho}^{3+} + 3e^- = \text{Ho}$	-2.23	
<b>Hydrogen</b>		
$2\text{H}^+ + 2e^- = \text{H}_2$	0.0000	
$2\text{D}^+ + 2e^- = \text{D}_2$	0.029	
$2\text{H}_2\text{O} + 2e^- = \text{H}_2 + 2\text{OH}^-$	-0.828	
<b>Indium</b>		
$\text{In}^{3+} + 3e^- = \text{In}$	-0.338	
$\text{In}^{3+} + 2e^- = \text{In}^+$	-0.444	
$\text{In}^+ + e^- = \text{In}$	-0.126	
<b>Iodine</b>		
$\text{H}_3\text{IO}_6 + \text{H}^+ + 2e^- = \text{IO}_3^- + 3\text{H}_2\text{O}$	1.603	
$\text{IO}_3^- + 5\text{H}^+ + 4e^- = \text{HIO} + 2\text{H}_2\text{O}$	1.14	
$\text{HIO}_3 + 5\text{H}^+ + 2\text{Cl}^- + 4e^- = \text{ICl}_2^- + 3\text{H}_2\text{O}$	1.214	
$2\text{IO}_3^- + 12\text{H}^+ + 10e^- = \text{I}_2(\text{c}) + 3\text{H}_2\text{O}$	1.195	
$\text{IO}_3^- + 3\text{H}_2\text{O} + 6e^- = \text{I}^- + 6\text{OH}^-$	0.257	
$2\text{IBr}_2^- + 2e^- = \text{I}_2\text{Br}^- + 3\text{Br}^-$	0.821	
$2\text{IBr}_2^- + 2e^- = \text{I}_2(\text{c}) + 4\text{Br}^-$	0.874	
$2\text{IBr} + 2e^- = \text{I}_2\text{Br}^- + \text{Br}^-$	0.973	
$2\text{IBr} + 2e^- = \text{I}_2 + 2\text{Br}^-$	1.02	
$2\text{ICl} + 2e^- = \text{I}_2(\text{c}) + 2\text{Cl}^-$	1.20	



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

Half-reaction	Standard or formal potential	Solution composition
$2\text{ICl}_2^- + 2e^- = \text{I}_2(\text{c}) + 4\text{Cl}^-$	1.07	
$2\text{ICN} + 2\text{H}^+ + 2e^- = \text{I}_2(\text{c}) + 2\text{HCN}$	0.695	
$2\text{ICN} + 2\text{H}^+ + 2e^- = \text{I}_2(\text{aq}) + 2\text{HCN}$	0.609	
$2\text{HIO} + 2\text{H}^+ + 2e^- = \text{I}_2 + 2\text{H}_2\text{O}$	1.45	
$\text{HIO} + \text{H}^+ + 2e^- = \text{I}^- + \text{H}_2\text{O}$	0.985	
$\text{I}_3^- + 2e^- = 3\text{I}^-$	0.536	
$\text{I}_2(\text{aq}) + 2e^- = 2\text{I}^-$	0.621	
$\text{I}_2(\text{c}) + 2e^- = 2\text{I}^-$	0.5355	
<b>Iridium</b>		
$\text{IrBr}_6^{2-} + e^- = \text{IrBr}_6^{3-}$	0.805	
$\text{IrCl}_6^{2-} + e^- = \text{IrCl}_6^{3-}$	0.867	
$\text{IrI}_6^{2-} + e^- = \text{IrI}_6^{3-}$	0.49	
$\text{IrO}_2 + 4\text{H}^+ + e^- = \text{Ir}^{3+} + 2\text{H}_2\text{O}$	0.223	
$\text{IrO}_2 + 4\text{H}^+ + 4e^- = \text{Ir} + 2\text{H}_2\text{O}$	0.935	1 H <sub>2</sub> SO <sub>4</sub>
$\text{Ir}^{3+} + 3e^- = \text{Ir}$	1.156	
$\text{IrCl}_6^{2-} + 4e^- = \text{Ir} + 6\text{Cl}^-$	0.835	
$\text{IrCl}_6^{3-} + 3e^- = \text{Ir} + 6\text{Cl}^-$	0.77	
<b>Iron</b>		
$\text{FeO}_4^{2-} + 8\text{H}^+ + 3e^- = \text{Fe}^{3+} + 4\text{H}_2\text{O}$	2.2	
$\text{FeO}_4^{2-} + 2\text{H}_2\text{O} + 3e^- = \text{FeO}_2^- + 4\text{OH}^-$	0.55	10 NaOH
$\text{Fe}^{3+} + e^- = \text{Fe}^{2+}$	0.771	
	0.70	1 HCl
	0.67	0.5 H <sub>2</sub> SO <sub>4</sub>
	0.44	0.3 H <sub>3</sub> PO <sub>4</sub>
$\text{Fe}(\text{CN})_6^{3-} + e^- = \text{Fe}(\text{CN})_6^{4-}$	0.361	
	0.71	1 HCl
$\text{Fe}(\text{EDTA})^- + e^- = \text{Fe}(\text{EDTA})^{2-}$	0.12	0.1 EDTA, pH 4–6
$\text{Fe}(\text{OH})_4^- + e^- = \text{Fe}(\text{OH})_3$	-0.73	1 NaOH
$\text{Fe}^{2+} + 2e^- = \text{Fe}$	-0.44	
$[\text{Fe}(\text{CO})_4]_3 + 6e^- = 3\text{Fe}(\text{CO})_4^{2-}$	-0.70	
<b>Lanthanum</b>		
$\text{La}^{3+} + 3e^- = \text{La}$	-2.38	
<b>Lawrencium</b>		
$\text{Lr}^{3+} + 3e^- = \text{Lr}$	-2.0	
<b>Lead</b>		
$\text{Pb}^{4+} + 2e^- = \text{Pb}^{2+}$	1.65	
$\text{PbO}_2(\text{alpha}) + \text{SO}_4^{2-} + 4\text{H}^+ + 2e^- = \text{PbSO}_4 + 2\text{H}_2\text{O}$	1.690	
$\text{PbO}_2 + 4\text{H}^+ + 2e^- = \text{Pb}^{2+} + 2\text{H}_2\text{O}$	1.46	
$\text{PbO}_2 + 2\text{H}^+ + 2e^- = \text{PbO} + \text{H}_2\text{O}$	0.28	
$\text{PbO}_2^{2-} + \text{H}_2\text{O} + 2e^- = \text{HPbO}_2^- + 3\text{OH}^-$	0.3	2 NaOH
$\text{Pb}^{2+} + 2e^- = \text{Pb}$	-0.126	
$\text{HPbO}_2^- + \text{H}_2\text{O} + 2e^- = \text{Pb} + 3\text{OH}^-$	-0.54	
$\text{PbHPO}_4 + 2e^- = \text{Pb} + \text{HPO}_4^{2-}$	-0.465	
$\text{PbSO}_4 + 2e^- = \text{Pb} + \text{SO}_4^{2-}$	-0.356	
$\text{PbF}_2 + 2e^- = \text{Pb} + 2\text{F}^-$	-0.344	
$\text{PbCl}_2 + 2e^- = \text{Pb} + 2\text{Cl}^-$	-0.268	
$\text{PbBr}_2 + 2e^- = \text{Pb} + 2\text{Br}^-$	-0.280	
$\text{PbI}_2 + 2e^- = \text{Pb} + 2\text{I}^-$	-0.365	
$\text{Pb} + 2\text{H}^+ + 2e^- = \text{PbH}_2$	-1.507	

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

Half-reaction	Standard or formal potential	Solution composition
<b>Lithium</b>		
$\text{Li}^+ + e^- = \text{Li}$	-3.040	
$\text{Li}^+ + \text{Hg} + e^- = \text{Li}(\text{Hg})$	-2.00	
<b>Lutetium</b>		
$\text{Lu}^{3+} + 3e^- = \text{Lu}$	-2.30	
<b>Magnesium</b>		
$\text{Mg}^{2+} + 2e^- = \text{Mg}$	-2.356	
$\text{Mg}(\text{OH})_2 + 2e^- = \text{Mg} + 2\text{OH}^-$	-2.687	
<b>Manganese</b>		
$\text{MnO}_4^- + e^- = \text{MnO}_4^{2-}$	0.56	
$\text{MnO}_4^- + 4\text{H}^+ + 3e^- = \text{MnO}_2(\text{beta}) + 2\text{H}_2\text{O}$	1.70	
$\text{MnO}_4^- + 2\text{H}_2\text{O} + 3e^- = \text{MnO}_2 + 4\text{OH}^-$	0.60	
$\text{MnO}_4^- + 8\text{H}^+ + 5e^- = \text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.51	
$\text{MnO}_4^{2-} + e^- = \text{MnO}_4^{3-}$	0.27	
$\text{MnO}_4^{2-} + 2\text{H}_2\text{O} + 2e^- = \text{MnO}_2 + 4\text{OH}^-$	0.62	
$\text{MnO}_4^{3-} + 2\text{H}_2\text{O} + e^- = \text{MnO}_2 + 4\text{OH}^-$	0.96	
$\text{MnO}_2 + 4\text{H}^+ + e^- = \text{Mn}^{3+} + 2\text{H}_2\text{O}$	0.95	
$\text{MnO}_2(\text{beta}) + 4\text{H}^+ + 2e^- = \text{Mn}^{2+} + 2\text{H}_2\text{O}$	1.23	
$\text{Mn}^{3+} + e^- = \text{Mn}^{2+}$	1.5	
$\text{Mn}(\text{H}_2\text{P}_2\text{O}_7)_3^{3-} + 2\text{H}^+ + e^- = \text{Mn}(\text{H}_2\text{P}_2\text{O}_7)_2^{2-} + \text{H}_4\text{P}_2\text{O}_7$	1.15	0.4 $\text{H}_2\text{P}_2\text{O}_7^{2-}$
$\text{Mn}(\text{CN})_6^{3-} + e^- = \text{Mn}(\text{CN})_6^{4-}$	-0.24	1.5 NaCN
$\text{Mn}^{2+} + 2e^- = \text{Mn}$	-1.17	
<b>Mendelevium</b>		
$\text{Md}^{3+} + 3e^- = \text{Md}$	-1.7	
$\text{Md}^{3+} + e^- = \text{Md}^{2+}$	-0.15	
$\text{Md}^{2+} + 2e^- = \text{Md}$	-2.4	
<b>Mercury</b>		
$2\text{Hg}^{2+} + 2e^- = \text{Hg}_2^{2+}$	0.911	
$2\text{HgCl}_2 + 2e^- = \text{Hg}_2\text{Cl}_2 + 2\text{Cl}^-$	0.63	
$\text{Hg}^{2+} + 2e^- = \text{Hg}(\text{lq})$	0.8535	
$\text{HgO}(\text{c,red}) + 2\text{H}^+ + 2e^- = \text{Hg} + \text{H}_2\text{O}$	0.926	
$\text{Hg}_2^{2+} + 2e^- = 2\text{Hg}$	0.7960	
$\text{Hg}_2\text{F}_2 + 2e^- = 2\text{Hg} + 2\text{F}^-$	0.656	
$\text{Hg}_2\text{Cl}_2 + 2e^- = 2\text{Hg} + 2\text{Cl}^-$	0.2682	
$\text{Hg}_2\text{Br}_2 + 2e^- = 2\text{Hg} + 2\text{Br}^-$	0.1392	
$\text{Hg}_2\text{I}_2 + 2e^- = 2\text{Hg} + 2\text{I}^-$	-0.0405	
$\text{Hg}_2\text{SO}_4 + 2e^- = 2\text{Hg} + \text{SO}_4^{2-}$	0.614	
<b>Molybdenum</b>		
$\text{MoO}_4^{2-} + 4\text{H}_2\text{O} + 6e^- = \text{Mo} + 8\text{OH}^-$	-0.913	
$\text{H}_2\text{MoO}_4 + 6\text{H}^+ + 6e^- = \text{Mo} + 4\text{H}_2\text{O}$	0.114	
$\text{H}_2\text{MoO}_4 + 2\text{H}^+ + 2e^- = \text{MoO}_2 + 2\text{H}_2\text{O}$	0.646	
$\text{MoO}_2 + 4\text{H}^+ + 4e^- = \text{Mo} + 2\text{H}_2\text{O}$	-0.152	
$\text{H}_2\text{MoO}_4 + 6\text{H}^+ + 3e^- = \text{Mo}^{3+} + 4\text{H}_2\text{O}$	0.428	
$\text{Mo}(\text{CN})_6^{3-} + e^- = \text{Mo}(\text{CN})_6^{4-}$	0.725	
$\text{Mo}^{3+} + 3e^- = \text{Mo}$	-0.2	
<b>Neodymium</b>		
$\text{Nd}^{3+} + 3e^- = \text{Nd}$	-2.32	
$\text{Nd}^{3+} + e^- = \text{Nd}^{2+}$	-2.6	
$\text{Nd}^{2+} + 2e^- = \text{Nd}$	-2.2	

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

Half-reaction	Standard or formal potential	Solution composition
<b>Neptunium</b>		
$\text{NpO}_3^+ + 2\text{H}^+ + e^- = \text{NpO}_2^+ + \text{H}_2\text{O}$	2.04	
$\text{NpO}_2^+ + e^- = \text{NpO}_2^+$	1.34	
$\text{NpO}_2^+ + 4\text{H}^+ + 2e^- = \text{Np}^{4+} + 2\text{H}_2\text{O}$	0.95	
$\text{Np}^{4+} + e^- = \text{Np}^{3+}$	0.18	
$\text{Np}^{4+} + 4e^- = \text{Np}$	-1.30	
$\text{Np}^{3+} + 3e^- = \text{Np}$	-1.79	
<b>Nickel</b>		
$\text{NiO}_2^- + 4\text{H}^+ + 2e^- = \text{NiO}_2 + 2\text{H}_2\text{O}$	1.8	
$\text{NiO}_2 + 4\text{H}^+ + 2e^- = \text{Ni}^{2+} + 2\text{H}_2\text{O}$	1.593	
$\text{NiO}_2 + 2\text{H}_2\text{O} + 2e^- = \text{Ni}(\text{OH})_2 + 2\text{OH}^-$	0.490	
$\text{Ni}(\text{CN})_4^{2-} + e^- = \text{Ni}(\text{CN})_3^- + \text{CN}^-$	-0.401	
$\text{Ni}^{2+} + 2e^- = \text{Ni}$	-0.257	
$\text{Ni}(\text{OH})_2 + 2e^- = \text{Ni} + 2\text{OH}^-$	-0.72	
$\text{Ni}(\text{NH}_3)_6^{2+} + 2e^- = \text{Ni} + 6\text{NH}_3$	-0.49	
<b>Niobium</b>		
$\text{Nb}_2\text{O}_5 + 10\text{H}^+ + 4e^- = 2\text{Nb}^{3+} + 5\text{H}_2\text{O}$	-0.1	
$\text{Nb}_2\text{O}_5 + 10\text{H}^+ + 10e^- = 2\text{Nb} + 5\text{H}_2\text{O}$	-0.65	
$\text{Nb}^{3+} + 3e^- = \text{Nb}$	-1.1	
<b>Nitrogen</b>		
$2\text{NO}_3^- + 4\text{H}^+ + 2e^- = \text{N}_2\text{O}_4 + 2\text{H}_2\text{O}$	0.803	
$\text{NO}_3^- + 3\text{H}^+ + 2e^- = \text{HNO}_2 + \text{H}_2\text{O}$	0.94	
$\text{N}_2\text{O}_4 + 2\text{H}^+ + 2e^- = 2\text{HNO}_2$	1.07	
$\text{HNO}_2 + \text{H}^+ + e^- = \text{NO} + \text{H}_2\text{O}$	0.996	
$2\text{HNO}_2 + 4\text{H}^+ + 4e^- = \text{N}_2\text{O}(\text{g}) + 3\text{H}_2\text{O}$	1.297	
$2\text{HNO}_2 + 4\text{H}^+ + 4e^- = \text{H}_2\text{N}_2\text{O}_2 + 2\text{H}_2\text{O}$	0.86	
$2\text{NO} + 2\text{H}^+ + 2e^- = \text{H}_2\text{N}_2\text{O}_2$	0.71	
$2\text{NO} + 2\text{H}^+ + 2e^- = \text{N}_2\text{O} + \text{H}_2\text{O}$	1.59	
$\text{H}_2\text{N}_2\text{O}_2 + 6\text{H}^+ + 4e^- = 2\text{HONH}_3^+$	0.496	
$\text{N}_2\text{O} + 2\text{H}^+ + 2e^- = \text{N}_2 + \text{H}_2\text{O}$	1.77	
$\text{N}_2\text{O} + 6\text{H}^+ + \text{H}_2\text{O} + 4e^- = 2\text{HONH}_3^+$	-0.05	
$\text{N}_2 + 2\text{H}_2\text{O} + 4\text{H}^+ + 2e^- = 2\text{HONH}_3^+$	-1.87	
$\text{N}_2 + 5\text{H}^+ + 4e^- = \text{N}_2\text{H}_5^+$	-0.23	
$\text{HONH}_3^+ + 2\text{H}^+ + 2e^- = \text{NH}_4^+ + \text{H}_2\text{O}$	1.35	
$2\text{HONH}_3^+ + \text{H}^+ + 2e^- = \text{N}_2\text{H}_5^+ + 2\text{H}_2\text{O}$	1.41	
$\text{N}_2\text{H}_5^+ + 3\text{H}^+ + 2e^- = 2\text{NH}_4^+$	1.275	
$3\text{N}_2 + 2\text{H}^+ + 2e^- = 2\text{HN}_3$	-3.40	
<b>Nobelium</b>		
$\text{No}^{3+} + 3e^- = \text{No}$	-1.2	
$\text{No}^{3+} + e^- = \text{No}^{2+}$	1.4	
$\text{No}^{2+} + 2e^- = \text{No}$	-2.5	
<b>Osmium</b>		
$\text{OsO}_4(\text{aq}) + 4\text{H}^+ + 4e^- = \text{OsO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_2\text{O}$	0.964	
$\text{OsO}_4(\text{c, yellow}) + 8\text{H}^+ + 8e^- = \text{Os} + 4\text{H}_2\text{O}$	0.85	
$\text{OsO}_2 + 4\text{H}^+ + 4e^- = \text{Os} + 2\text{H}_2\text{O}$	0.687	
$\text{OsCl}_6^{2-} + e^- = \text{OsCl}_6^{3-}$	0.45	
$\text{OsBr}_6^- + e^- = \text{OsBr}_6^{2-}$	0.35	
<b>Oxygen</b>		
$\text{O}_3 + 2\text{H}^+ + 2e^- = \text{O}_2 + \text{H}_2\text{O}$	2.075	
$\text{O}_3 + \text{H}_2\text{O} + 2e^- = \text{O}_2 + 2\text{OH}^-$	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	
<b>Palladium</b>		
$PdO_3 + 2H^+ + 2e^- = PdO_2 + H_2O$	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 <sub>3</sub>
$Pd(CN)_4^{2-} + 2e^- = Pd + 4CN^-$	-1.35	1 KCN
<b>Phosphorus</b>		
$H_3PO_4 + 2H^+ + 2e^- = H_3PO_3 + H_2O$	-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	
$2P(\text{white}) + 4H^+ + 4e^- = P_2H_4$	-0.100	
$P_2H_4 + 2H^+ + 2e^- = 2PH_3$	-0.006	
$P(\text{white}) + 3H^+ + 3e^- = PH_3$	-0.063	
<b>Platinum</b>		
$PtO_3 + 2H^+ + 2e^- = PtO_2 + H_2O$	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	
<b>Plutonium</b>		
$PuO_2^{2+} + e^- = PuO_2^+$	1.02	
$PuO_2^{2+} + 4H^+ + 2e^- = Pu^{4+} + 2H_2O$	1.04	
$Pu^{4+} + e^- = Pu^{3+}$	1.01	
	0.80	1 H <sub>3</sub> PO <sub>4</sub>
	0.50	1 HF
$Pu^{4+} + 4e^- = Pu$	-1.25	
$Pu^{3+} + 3e^- = Pu$	-2.00	
<b>Polonium</b>		
$PoO_2 + 4H^+ + 2e^- = Po^{2+} + 2H_2O$	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
<b>Potassium</b>		
$K^+ + e^- = K$	-2.924	
$K^+ + Hg + e^- = K(Hg)$	ca. -1.9	
<b>Praseodymium</b>		
$Pr^{4+} + e^- = Pr^{3+}$	3.2	
$Pr^{3+} + e^- = Pr$	-2.35	
<b>Promethium</b>		
$Pm^{3+} + 3e^- = Pm$	-2.42	
<b>Protoactinium</b>		
$PaOOH^{2+} + 3H^+ + e^- = Pa^{4+} + 2H_2O$	-0.10	
$PaOOH^{2+} + 3H^+ + 5e^- = Pa + 2H_2O$	-1.19	
$Pa^{4+} + 4e^- = Pa$	-1.46	
<b>Radium</b>		
$Ra^{2+} + 2e^- = Ra$	-2.916	
<b>Rhenium</b>		
$ReO_4^- + 2H^+ + e^- = ReO_3 + H_2O$	0.768	
$ReO_4^- + 4H^+ + 3e^- = ReO_2 + 2H_2O$	0.51	
$ReO_4^- + 2H_2O + 3e^- = ReO_2 + 4OH^-$	-0.594	
$ReO_4^- + 6Cl^- + 8H^+ + 3e^- = ReCl_6^{3-} + 4H_2O$	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	
$ReCl_6^{3-} + 4e^- = Re + 6Cl^-$	0.51	
$Re + e^- = Re^-$	-0.10	
<b>Rhodium</b>		
$RhO_2 + 4H^+ + e^- = Rh^{3+} + 2H_2O$	1.881	
$Rh^{3+} + 3e^- = Rh$	0.76	
$RhCl_6^{3-} + 3e^- = Rh + 6Cl^-$	0.5	
<b>Rubidium</b>		
$Rb^+ + e^- = Rb$	-2.924	
$Rb^+ + Hg + e^- = Rb(Hg)$	-1.81	
<b>Ruthenium</b>		
$RuO_4 + e^- = RuO_4^-$	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	
<b>Samarium</b>		
$Sm^{3+} + 3e^- = Sm$	-2.30	
$Sm^{3+} + e^- = Sm^{2+}$	-1.55	
$Sm^{2+} + 2e^- = Sm$	-2.67	
<b>Scandium</b>		
$Sc^{3+} + 3e^- = Sc$	-2.03	

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

Half-reaction	Standard or formal potential	Solution composition
<b>Selenium</b>		
$\text{SeO}_4^{2-} + 4\text{H}^+ + 2e^- = \text{H}_2\text{SeO}_3 + \text{H}_2\text{O}$	1.151	1 NaOH
$\text{H}_2\text{SeO}_3 + 4\text{H}^+ + 4e^- = \text{Se} + 3\text{H}_2\text{O}$	0.74	
$\text{Se}(c) + 2\text{H}^+ + 2e^- = \text{H}_2\text{Se}(aq)$	-0.115	
$\text{Se} + \text{H}^+ + 2e^- = \text{HSe}^-$	-0.227	
$\text{Se} + 2e^- = \text{Se}^{2-}$	-0.670	
<b>Silicon</b>		
$\text{SiO}_2(\text{quartz}) + 4\text{H}^+ + 4e^- = \text{Si} + 2\text{H}_2\text{O}$	-0.909	1 NaOH
$\text{SiO}_2 + 2\text{H}^+ + 2e^- = \text{SiO} + \text{H}_2\text{O}$	-0.967	
$\text{SiO}_2 + 8\text{H}^+ + 8e^- = \text{SiH}_4 + 2\text{H}_2\text{O}$	-0.516	
$\text{SiF}_6^{2-} + 4e^- = \text{Si} + 6\text{F}^-$	-1.37	
$\text{SiO} + 2\text{H}^+ + 2e^- = \text{Si} + \text{H}_2\text{O}$	-0.808	
$\text{Si} + 4\text{H}^+ + 4e^- = \text{SiH}_4(g)$	-0.143	
<b>Silver</b>		
$\text{AgO}^+ + 2\text{H}^+ + e^- = \text{Ag}^{2+} + \text{H}_2\text{O}$	1.360	1 NaOH
$\text{Ag}_2\text{O}_3 + 2\text{H}^+ + 2e^- = 2\text{AgO} + \text{H}_2\text{O}$	1.569	
$\text{Ag}_2\text{O}_3 + \text{H}_2\text{O} + 2e^- = 2\text{AgO} + 2\text{OH}^-$	0.739	
$\text{Ag}_2\text{O}_3 + 6\text{H}^+ + 4e^- = 2\text{Ag}^+ + 3\text{H}_2\text{O}$	1.670	
$\text{Ag}^{2+} + e^- = \text{Ag}^+$	1.980	
$\text{AgO} + 2\text{H}^+ + e^- = \text{Ag}^+ + \text{H}_2\text{O}$	1.772	
$\text{Ag}^+ + e^- = \text{Ag}$	0.7991	
$\text{Ag}_2\text{SO}_4 + 2e^- = 2\text{Ag} + \text{SO}_4^{2-}$	0.653	
$\text{Ag}_2\text{C}_2\text{O}_4 + 2e^- = 2\text{Ag} + \text{C}_2\text{O}_4^{2-}$	0.47	
$\text{Ag}_2\text{CrO}_4 + 2e^- = 2\text{Ag} + \text{CrO}_4^{2-}$	0.447	
$\text{Ag}(\text{NH}_3)_2^+ + e^- = \text{Ag} + 2\text{NH}_3$	0.373	
$\text{AgCl} + e^- = \text{Ag} + \text{Cl}^-$	0.2223	
$\text{AgBr} + e^- = \text{Ag} + \text{Br}^-$	0.071	
$\text{AgCN} + e^- = \text{Ag} + \text{CN}^-$	-0.017	
$\text{AgI} + e^- = \text{Ag} + \text{I}^-$	-0.152	
$\text{Ag}(\text{CN}) + e^- = \text{Ag} + 2\text{CN}^-$	-0.31	
$\text{AgSCN} + e^- = \text{Ag} + \text{SCN}^-$	0.09	
$\text{Ag}_2\text{S} + 2e^- = 2\text{Ag} + \text{S}^{2-}$	-0.71	
<b>Sodium</b>		
$\text{Na}^+ + e^- = \text{Na}$	-2.713	1 NaOH
$\text{Na}^+ + \text{Hg} + e^- = \text{Na}(\text{Hg})$	-1.84	
<b>Strontium</b>		
$\text{SrO}_2 + 4\text{H}^+ + 2e^- = \text{Sr}^{2+}$	2.33	1 NaOH
$\text{Sr}^{2+} + 2e^- = \text{Sr}$	-2.89	
<b>Sulfur</b>		
$\text{S}_2\text{O}_8^{2-} + 2e^- = 2\text{SO}_4^{2-}$	1.96	1 NaOH
$\text{S}_2\text{O}_8^{2-} + 2\text{H}^+ + 2e^- = 2\text{HSO}_4^-$	2.08	
$2\text{SO}_4^{2-} + 4\text{H}^+ + 2e^- = \text{S}_2\text{O}_6^{2-} + 2\text{H}_2\text{O}$	-0.25	
$\text{SO}_4^{2-} + 4\text{H}^+ + 2e^- = \text{SO}_2(aq) + \text{H}_2\text{O}$	0.158	
$\text{SO}_4^{2-} + \text{H}_2\text{O} + 2e^- = \text{SO}_3^{2-} + 2\text{OH}^-$	-0.936	
$\text{S}_2\text{O}_6^{2-} + 4\text{H}^+ + 2e^- = 2\text{H}_2\text{SO}_3$	0.569	
$\text{S}_2\text{O}_6^{2-} + 2e^- = 2\text{SO}_3^{2-}$	0.037	
$2\text{HSO}_3^- + 2\text{H}^+ + 2e^- = \text{S}_2\text{O}_4^{2-} + 2\text{H}_2\text{O}$	0.099	
$2\text{SO}_3^{2-} + 2\text{H}_2\text{O} + 2e^- = \text{S}_2\text{O}_4^{2-} + 4\text{OH}^-$	-1.13	
$4\text{H}_2\text{SO}_3 + 4\text{H}^+ + 6e^- = \text{S}_4\text{O}_6^{2-} + 6\text{H}_2\text{O}$	0.507	

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

Half-reaction	Standard or formal potential	Solution composition
$4\text{HSO}_3^- + 8\text{H}^+ + 6e^- = \text{S}_4\text{O}_6^{2-} + 6\text{H}_2\text{O}$	0.577	
$2\text{SO}_2(\text{aq}) + 2\text{H}^+ + 4e^- = \text{S}_2\text{O}_3^{2-} + \text{H}_2\text{O}$	0.400	
$2\text{SO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- = \text{S}_2\text{O}_3^{2-} + 6\text{OH}^-$	-0.576	1 NaOH
$\text{SO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- = \text{S} + 6\text{OH}^-$	-0.59	1 NaOH
$\text{S}_4\text{O}_6^{2-} + 2e^- = 2\text{S}_2\text{O}_3^{2-}$	0.080	
$\text{S}_2\text{O}_3^{2-} + 6\text{H}^+ + 4e^- = 2\text{S} + 3\text{H}_2\text{O}$	0.5	
$\text{SF}_4(\text{g}) + 4e^- = \text{S} + 4\text{F}^-$	0.97	
$\text{S}_2\text{Cl}_2(\text{g}) + 2e^- = 2\text{S} + 2\text{Cl}^-$	1.19	
$\text{S} + \text{H}^+ + 2e^- = \text{HS}^-$	0.287	
$\text{S} + 2\text{H}^+ + 2e^- = \text{H}_2\text{S}(\text{aq})$	0.144	
$\text{S} + 2\text{H}^+ + 2e^- = \text{H}_2\text{S}(\text{g})$	0.174	
$\text{S} + 2e^- = \text{S}^{2-}$	-0.407	
<b>Tantalum</b>		
$\text{Ta}_2\text{O}_5 + 10\text{H}^+ + 10e^- = 2\text{Ta} + 5\text{H}_2\text{O}$	-0.81	
$\text{TaF}_7^{2-} + 5e^- = \text{Ta} + 7\text{F}^-$	-0.45	
<b>Technetium</b>		
$\text{TcO}_4^- + 4\text{H}^+ + 3e^- = \text{TcO}_2 + 2\text{H}_2\text{O}$	0.738	
$\text{TcO}_4^- + 2\text{H}^+ + e^- = \text{TcO}_3 + \text{H}_2\text{O}$	0.700	
$\text{TcO}_4^- + e^- = \text{TcO}_4^{2-}$	0.569	
$\text{TcO}_4^- + 8\text{H}^+ + 7e^- = \text{Tc} + 4\text{H}_2\text{O}$	0.472	
$\text{TcO}_2^{2-} + 4\text{H}^+ + 2e^- = \text{TcO}_2 + 2\text{H}_2\text{O}$	1.39	
$\text{TcO}_2 + 4\text{H}^+ + 4e^- = \text{Tc} + 2\text{H}_2\text{O}$	0.272	
$\text{Tc} + e^- = \text{Tc}^-$	ca. -0.5	
<b>Tellurium</b>		
$\text{H}_2\text{TeO}_4 + 6\text{H}^+ + 2e^- = \text{Te}^{4+} + 4\text{H}_2\text{O}$	0.929	
$\text{H}_2\text{TeO}_4 + 2\text{H}^+ + 2e^- = \text{TeO}_2(\text{c}) + 2\text{H}_2\text{O}$	1.02	
$\text{TeO}_4^{2-} + 2\text{H}^+ + 2e^- = \text{TeO}_3^{2-} + \text{H}_2\text{O}$	0.897	
$\text{TeOOH}^+ + 3\text{H}^+ + 4e^- = \text{Te} + 2\text{H}_2\text{O}$	0.559	
$\text{H}_2\text{TeO}_3 + 4\text{H}^+ + 4e^- = \text{Te} + 3\text{H}_2\text{O}$	0.589	
$\text{TeO}_3^{2-} + 6\text{H}^+ + 4e^- = \text{Te} + 3\text{H}_2\text{O}$	0.827	
$\text{TeO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- = \text{Te} + 6\text{OH}^-$	-0.415	
$\text{TeO}_2(\text{c}) + 4\text{H}^+ + 4e^- = \text{Te} + 2\text{H}_2\text{O}$	0.521	
$\text{Te} + 2\text{H}^+ + 2e^- = \text{H}_2\text{Te}(\text{aq})$	-0.740	
$\text{Te} + \text{H}^+ + 2e^- = \text{HTe}^-$	-0.817	
$\text{Te}^{2-} + 2\text{H}^+ + 2e^- = 2\text{HTe}^-$	-0.794	
<b>Terbium</b>		
$\text{Tb}^{3+} + 3e^- = \text{Tb}$	-2.31	
<b>Thallium</b>		
$\text{Tl}^{3+} + 2e^- = \text{Tl}^+$	1.25	1 HClO <sub>4</sub>
	0.77	1 HCl
$\text{Tl}^{3+} + 3e^- = \text{Tl}$	0.72	
$\text{Tl}^+ + e^- = \text{Tl}$	-0.336	
$\text{TlCl} + e^- = \text{Tl} + \text{Cl}^-$	-0.557	
$\text{TlBr} + e^- = \text{Tl} + \text{Br}^-$	-0.658	
$\text{TlI} + e^- = \text{Tl} + \text{I}^-$	-0.752	
<b>Thorium</b>		
$\text{Th}^{4+} + 4e^- = \text{Th}$	-1.83	

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

Half-reaction	Standard or formal potential	Solution composition
<b>Thullium</b>		
$\text{Tm}^{3+} + 3e^- = \text{Tm}$	-2.32	
<b>Tin</b>		
$\text{Sn}^{4+} + 2e^- = \text{Sn}^{2+}$	0.154	
$\text{SnCl}_6^{2-} + 2e^- = \text{SnCl}_4^{2-} + 2\text{Cl}^-$	0.14	
$\text{SnO}_3^{2-} + 6\text{H}^+ + 2e^- = \text{Sn}^{2+} + 3\text{H}_2\text{O}$	0.849	
$\text{SnF}_6^{2-} + 4e^- = \text{Sn} + 6\text{F}^-$	-0.200	
$\text{Sn}^{2+} + 2e^- = \text{Sn}$	-0.1375	
$\text{SnCl}_4^{2-} + 2e^- = \text{Sn} + 4\text{Cl}^-$	-0.19	
$\text{HSnO}_2 + \text{H}_2\text{O} + 2e^- = \text{Sn} + 3\text{OH}^-$	-0.91	1 HCl
$\text{Sn} + 4\text{H}^+ + 4e^- = \text{SnH}_4$	-1.07	
<b>Titanium</b>		
$\text{TiO}^{2+} + 2\text{H}^+ + e^- = \text{Ti}^{3+} + \text{H}_2\text{O}$	-0.10	
$\text{TiO}^{2+} + 2\text{H}^+ + 4e^- = \text{Ti} + \text{H}_2\text{O}$	-0.86	
$\text{Ti}^{3+} + e^- = \text{Ti}^{2+}$	-0.37	
$\text{Ti}^{3+} + 3e^- = \text{Ti}$	-1.21	
$\text{Ti}^{2+} + 2e^- = \text{Ti}$	-1.63	
<b>Tungsten</b>		
$2\text{WO}_3 + 2\text{H}^+ + 2e^- = \text{W}_2\text{O}_5 + \text{H}_2\text{O}$	-0.029	
$\text{WO}_3 + 6\text{H}^+ + 6e^- = \text{W} + 3\text{H}_2\text{O}$	-0.090	
$\text{WO}_4^{2-} + 4\text{H}_2\text{O} + 6e^- = \text{W} + 8\text{OH}^-$	-1.074	
$\text{WO}_4^{2-} + 2\text{H}_2\text{O} + 2e^- = \text{WO}_2 + 4\text{OH}^-$	-1.259	
$\text{W}_2\text{O}_5 + 2\text{H}^+ + 2e^- = 2\text{WO}_2 + \text{H}_2\text{O}$	-0.031	
$\text{W}(\text{CN})_8^{3-} + e^- = \text{W}(\text{CN})_8^{4-}$	0.457	
$\text{WO}_2 + 4\text{H}^+ + 4e^- = \text{W} + 2\text{H}_2\text{O}$	-0.119	
$\text{WO}_2 + 2\text{H}_2\text{O} + 4e^- = \text{W} + 4\text{OH}^-$	-0.982	
<b>Uranium</b>		
$\text{UO}_2^{2+} + e^- = \text{UO}_2^+$	0.16	
$\text{UO}_2^{2+} + 4\text{H}^+ + 2e^- = \text{U}^{4+} + 2\text{H}_2\text{O}$	0.27	
$\text{UO}_2^+ + 4\text{H}^+ + e^- = \text{U}^{4+} + 2\text{H}_2\text{O}$	0.38	
$\text{U}^{4+} + e^- = \text{U}^{3+}$	-0.52	
$\text{U}^{4+} + 4e^- = \text{U}$	-1.38	
$\text{U}^{3+} + 3e^- = \text{U}$	-1.66	
<b>Vanadium</b>		
$\text{VO}_2^+ + 2\text{H}^+ + e^- = \text{VO}^{2+} + \text{H}_2\text{O}$	1.000	
$\text{VO}_2^+ + 4\text{H}^+ + 2e^- = \text{V}^{3+} + 2\text{H}_2\text{O}$	0.668	
$\text{VO}_2^+ + 4\text{H}^+ + 3e^- = \text{V}^{2+} + 2\text{H}_2\text{O}$	0.361	
$\text{VO}_2^+ + 4\text{H}^+ + 5e^- = \text{V} + 4\text{H}_2\text{O}$	-0.236	
$\text{VO}^{2+} + 2\text{H}^+ + e^- = \text{V}^{3+} + \text{H}_2\text{O}$	0.337	
$\text{V}^{3+} + e^- = \text{V}^{2+}$	-0.255	
$\text{V}^{2+} + 2e^- = \text{V}$	-1.13	
<b>Xenon</b>		
$\text{H}_4\text{XeO}_6 + 2\text{H}^+ + 2e^- = \text{XeO}_3 + 3\text{H}_2\text{O}$	2.42	
$\text{HXeO}_6^{3-} + 2\text{H}_2\text{O} + e^- = \text{HXeO}_4 + 4\text{OH}^-$	0.9	
$\text{XeO}_3 + 6\text{H}^+ + 2\text{F}^- + 4e^- = \text{XeF}_2 + 3\text{H}_2\text{O}$	1.6	
$\text{XeO}_3 + 6\text{H}^+ + 6e^- = \text{Xe}(\text{g}) + 3\text{H}_2\text{O}$	2.10	
$\text{XeF}_2 + e^- = \text{XeF} + \text{F}^-$	0.9	
$\text{XeF}_2 + 2\text{H}^+ + 2e^- = \text{Xe}(\text{g}) + 2\text{HF}$	2.64	
$\text{XeF} + e^- = \text{Xe}(\text{g}) + \text{F}^-$	3.4	



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

Half-reaction	Standard or formal potential	Solution composition
<b>Ytterbium</b>		
$\text{Yb}^{3+} + e^- = \text{Yb}^{2+}$	-1.05	
$\text{Yb}^{2+} + 2e^- = \text{Yb}$	-2.8	
$\text{Yb}^{3+} + 3e^- = \text{Yb}$	-2.22	
<b>Yttrium</b>		
$\text{Y}^{3+} + 3e^- = \text{Y}$	-2.37	
<b>Zinc</b>		
$\text{Zn}^{2+} + 2e^- = \text{Zn}$	-0.7626	
$\text{Zn}(\text{NH}_3)_4^{2+} + 2e^- = \text{Zn} + 4\text{NH}_3$	-1.04	
$\text{Zn}(\text{CN})_4^{2-} + 2e^- = \text{Zn} + 4\text{CN}^-$	-1.34	
$\text{Zn}(\text{tartrate})_4^{6-} + 2e^- = \text{Zn} + 4(\text{tartrate})^{2-}$	-1.15	
$\text{Zn}(\text{OH})_4^{2-} + 2e^- = \text{Zn} + 4\text{OH}^-$	-1.285	
<b>Zirconium</b>		
$\text{Zr}^{4+} + 4e^- = \text{Zr}$	-1.55	
$\text{ZrO}_2 + 4\text{H}^+ + 4e^- = \text{Zr} + 2\text{H}_2\text{O}$	-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	$E^\circ$ , volts
$\text{F}_2(\text{g}) + 2\text{H}^+ + 2e^- = 2\text{HF}$	3.053
$\text{O}_3 + \text{H}_2\text{O} + 2e^- = \text{O}_2 + 2\text{OH}^-$	1.246
$\text{O}_3 + 2\text{H}^+ + 2e^- = \text{O}_2 + \text{H}_2\text{O}$	2.075
$\text{Ag}^{2+} + e^- = \text{Ag}^+$	1.980
$\text{S}_2\text{O}_8^{2-} + 2e^- = 2\text{SO}_4^{2-}$	1.96
$\text{HN}_3 + 3\text{H}^+ + 2e^- = \text{NH}_4^+ + \text{N}_2$	1.96
$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2e^- = 2\text{H}_2\text{O}$	1.763
$\text{Ce}^{4+} + e^- = \text{Ce}^{3+}$	1.72
$\text{MnO}_4^- + 4\text{H}^+ + 3e^- = \text{MnO}_2(\text{c}) + 2\text{H}_2\text{O}$	1.70
$2\text{HClO} + 2\text{H}^+ + 2e^- = \text{Cl}_2 + \text{H}_2\text{O}$	1.630
$2\text{HBrO} + 2\text{H}^+ + 2e^- = \text{Br}_2 + \text{H}_2\text{O}$	1.604
$\text{H}_5\text{IO}_6 + \text{H}^+ + 2e^- = \text{IO}_3^- + 3\text{H}_2\text{O}$	1.603
$\text{NiO}_2 + 4\text{H}^+ + 2e^- = \text{Ni}^{2+} + 2\text{H}_2\text{O}$	1.593
$\text{Bi}_2\text{O}_4(\text{bismuthate}) + 4\text{H}^+ + 2e^- = 2\text{BiO}^+ + 2\text{H}_2\text{O}$	1.59
$\text{MnO}_4^- + 8\text{H}^+ + 5e^- = \text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.51
$2\text{BrO}_3^- + 12\text{H}^+ + 10e^- = \text{Br}_2 + 6\text{H}_2\text{O}$	1.478
$\text{PbO}_2 + 4\text{H}^+ + 2e^- = \text{Pb}^{2+} + 2\text{H}_2\text{O}$	1.468
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6e^- = 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	1.36
$\text{Cl}_2 + 2e^- = 2\text{Cl}^-$	1.3583
$2\text{HNO}_2 + 4\text{H}^+ + 4e^- = \text{N}_2\text{O} + 3\text{H}_2\text{O}$	1.297
$\text{N}_2\text{H}_5^+ + 3\text{H}^+ + 2e^- = 2\text{NH}_4^+$	1.275
$\text{MnO}_2 + 4\text{H}^+ + 2e^- = \text{Mn}^{2+} + 2\text{H}_2\text{O}$	1.23
$\text{O}_2 + 4\text{H}^+ + 4e^- = 2\text{H}_2\text{O}$	1.229
$\text{ClO}_4^- + 2\text{H}^+ + 2e^- = \text{ClO}_3^- + \text{H}_2\text{O}$	1.201

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

Half-reaction	$E^\circ$ , volts
$2\text{IO}_3^- + 12\text{H}^+ + 10e^- = \text{I}_2 + 3\text{H}_2\text{O}$	1.195
$\text{N}_2\text{O}_4 + 2\text{H}^+ + 2e^- = 2\text{HNO}_3$	1.07
$2\text{ICl}_2^- + 2e^- = 4\text{Cl}^- + \text{I}_2$	1.07
$\text{Br}_2(\text{lq}) + 2e^- = 2\text{Br}^-$	1.065
$\text{N}_2\text{O}_4 + 4\text{H}^+ + 4e^- = 2\text{NO} + 2\text{H}_2\text{O}$	1.039
$\text{HNO}_2 + \text{H}^+ + e^- = \text{NO} + \text{H}_2\text{O}$	0.996
$\text{NO}_3^- + 4\text{H}^+ + 3e^- = \text{NO} + 2\text{H}_2\text{O}$	0.957
$\text{NO}_3^- + 3\text{H}^+ + 2e^- = \text{HNO}_2 + \text{H}_2\text{O}$	0.94
$2\text{Hg}^{2+} + 2e^- = \text{Hg}_2^{2+}$	0.911
$\text{Cu}^{2+} + \text{I}^- + e^- = \text{CuI}$	0.861
$\text{OsO}_4(\text{c}) + 8\text{H}^+ + 8e^- = \text{Os} + 4\text{H}_2\text{O}$	0.84
$\text{Ag}^+ + e^- = \text{Ag}$	0.7991
$\text{Hg}_2^{2+} + 2e^- = 2\text{Hg}$	0.7960
$\text{Fe}^{3+} + e^- = \text{Fe}^{2+}$	0.771
$\text{H}_2\text{SeO}_3 + 4\text{H}^+ + 4e^- = \text{Se} + 3\text{H}_2\text{O}$	0.739
$\text{HN}_3 + 11\text{H}^+ + 8e^- = 2\text{NH}_4^+$	0.695
$\text{O}_2 + 2\text{H}^+ + 2e^- = \text{H}_2\text{O}_2$	0.695
$\text{Ag}_2\text{SO}_4 + 2e^- = 2\text{Ag} + \text{SO}_4^{2-}$	0.654
$\text{Cu}^{2+} + \text{Br}^- + e^- = \text{CuBr}(\text{c})$	0.654
$\text{Au}(\text{SCN})_4^- + 3e^- = \text{Au} + 4\text{SCN}^-$	0.636
$2\text{HgCl}_2 + 2e^- = \text{Hg}_2\text{Cl}_2(\text{c}) + 2\text{Cl}^-$	0.63
$\text{Sb}_2\text{O}_5 + 6\text{H}^+ + 4e^- = 2\text{SbO}^+ + 3\text{H}_2\text{O}$	0.605
$\text{H}_3\text{AsO}_4 + 2\text{H}^+ + 2e^- = \text{HAsO}_2 + 2\text{H}_2\text{O}$	0.560
$\text{TeOOH}^+ + 3\text{H}^+ + 4e^- = \text{Te} + 2\text{H}_2\text{O}$	0.559
$\text{Cu}^{2+} + \text{Cl}^- + e^- = \text{CuCl}(\text{c})$	0.559
$\text{I}_3^- + 2e^- = 3\text{I}^-$	0.536
$\text{I}_2 + 2e^- = 2\text{I}^-$	0.536
$\text{Cu}^+ + e^- = \text{Cu}$	0.53
$4\text{H}_2\text{SO}_3 + 4\text{H}^+ + 6e^- = \text{S}_4\text{O}_6^{2-} + 6\text{H}_2\text{O}$	0.507
$\text{Ag}_2\text{CrO}_4 + 2e^- = 2\text{Ag} + \text{CrO}_4^{2-}$	0.449
$2\text{H}_2\text{SO}_3 + 2\text{H}^+ + 4e^- = \text{S}_2\text{O}_3^{2-} + 3\text{H}_2\text{O}$	0.400
$\text{UO}_2^{2+} + 4\text{H}^+ + e^- = \text{U}^{4+} + 2\text{H}_2\text{O}$	0.38
$\text{Fe}(\text{CN})_6^{3-} + e^- = \text{Fe}(\text{CN})_6^{4-}$	0.361
$\text{Cu}^{2+} + 2e^- = \text{Cu}$	0.340
$\text{VO}^{2+} + 2\text{H}^+ + e^- = \text{V}^{3+} + \text{H}_2\text{O}$	0.337
$\text{BiO}^+ + 2\text{H}^+ + 3e^- = \text{Bi} + \text{H}_2\text{O}$	0.32
$\text{UO}_2^{3+} + 4\text{H}^+ + 2e^- = \text{U}^{4+} + 2\text{H}_2\text{O}$	0.27
$\text{Hg}_2\text{Cl}_2(\text{c}) + 2e^- = 2\text{Hg} + 2\text{Cl}^-$	0.2676
$\text{AgCl} + e^- = \text{Ag} + \text{Cl}^-$	0.2223
$\text{SbO}^+ + 2\text{H}^+ + 3e^- = \text{Sb} + \text{H}_2\text{O}$	0.212
$\text{CuCl}_2^- + e^- = \text{Cu} + 3\text{Cl}^-$	0.178
$\text{SO}_4^{2-} + 4\text{H}^+ + 2e^- = \text{H}_2\text{SO}_3 + \text{H}_2\text{O}$	0.158
$\text{Sn}^{4+} + 2e^- = \text{Sn}^{2+}$	0.15
$\text{S} + 2\text{H}^+ + 2e^- = \text{H}_2\text{S}$	0.144
$\text{Hg}_2\text{Br}_2(\text{c}) + 2e^- = 2\text{Hg} + 2\text{Br}^-$	0.1392
$\text{CuCl} + e^- = \text{Cu} + \text{Cl}^-$	0.121
$\text{TiO}^{2+} + 2\text{H}^+ + e^- = \text{Ti}^{3+} + \text{H}_2\text{O}$	0.100
$\text{S}_4\text{O}_6^{2-} + 2e^- = 2\text{S}_2\text{O}_3^{2-}$	0.08
$\text{AgBr} + e^- = \text{Ag} + \text{Br}^-$	0.0711
$\text{HCOOH} + 2\text{H}^+ + 2e^- = \text{HCHO} + \text{H}_2\text{O}$	0.056
$\text{CuBr} + e^- = \text{Cu} + \text{Br}^-$	0.033
$2\text{H}^+ + 2e^- = \text{H}_2$	0.0000
$\text{Hg}_2\text{I}_2 + 2e^- = 2\text{Hg} + 2\text{I}^-$	-0.0405

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

Half-reaction	$E^\circ$ , volts
$\text{Pb}^{2+} + 2e^- = \text{Pb}$	-0.125
$\text{Sn}^{2+} + 2e^- = \text{Sn}$	-0.136
$\text{AgI} + e^- = \text{Ag} + \text{I}^-$	-0.1522
$\text{N}_2 + 5\text{H}^+ + 4e^- = \text{N}_2\text{H}_5^+$	-0.225
$\text{V}^{3+} + e^- = \text{V}^{2+}$	-0.255
$\text{Ni}^{2+} + 2e^- = \text{Ni}$	-0.257
$\text{Co}^{2+} + 2e^- = \text{Co}$	-0.277
$\text{Ag}(\text{CN})_2^- + e^- = \text{Ag} + 2\text{CN}^-$	-0.31
$\text{PbSO}_4 + 2e^- = \text{Pb} + \text{SO}_4^{2-}$	-0.3505
$\text{Cd}^{2+} + 2e^- = \text{Cd}$	-0.4025
$\text{Cr}^{3+} + e^- = \text{Cr}^{2+}$	-0.424
$\text{Fe}^{2+} + 2e^- = \text{Fe}$	-0.44
$\text{H}_3\text{PO}_3 + 2\text{H}^+ + 2e^- = \text{H}_2\text{P}_2\text{O}_4 + \text{H}_2\text{O}$	-0.499
$2\text{CO}_2 + 2\text{H}^+ + 2e^- = \text{H}_2\text{C}_2\text{O}_4$	-0.49
$\text{U}^{4+} + e^- = \text{U}^{3+}$	-0.52
$\text{Zn}^{2+} + 2e^- = \text{Zn}$	-0.7626
$\text{Mn}^{2+} + 2e^- = \text{Mn}$	-1.18
$\text{Al}^{3+} + 3e^- = \text{Al}$	-1.67
$\text{Mg}^{2+} + 2e^- = \text{Mg}$	-2.356
$\text{Na}^+ + e^- = \text{Na}$	-2.714
$\text{K}^+ + e^- = \text{K}$	-2.925
$\text{Li}^+ + e^- = \text{Li}$	-3.045
$3\text{N}_2 + 2\text{H}^+ + 2e^- = 2\text{HN}_3$	-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/cm <sup>2</sup>					
	0.001	0.01	0.1	0.5	1.0	5.0
	Overpotential, volts					
<b>Liberation of H<sub>2</sub> from 1M H<sub>2</sub>SO<sub>4</sub></b>						
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	
<b>Liberation of O<sub>2</sub> from 1M KOH</b>						
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	
<b>Liberation of Cl<sub>2</sub> from saturated NaCl solution</b>						
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	
<b>Liberation of Br<sub>2</sub> from saturated NaBr solution</b>						
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†	
<b>Liberation of I<sub>2</sub> from saturated NaI solution</b>						
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/cm<sup>2</sup>. † At 0.72 A/cm<sup>2</sup>.

The overpotential required for the evolution of O<sub>2</sub> from dilute solutions of HClO<sub>4</sub>, HNO<sub>3</sub>, H<sub>3</sub>PO<sub>4</sub> or H<sub>2</sub>SO<sub>4</sub> 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
<b>Aluminum</b> 3+	-0.5	0.2M 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.
<b>Antimony</b> 3+ to 0	-0.15 -0.31(1) -0.8 -1.0; -1.2 -1.26 -1.32	1M HCl 1M HNO <sub>3</sub> (or 0.5M H <sub>2</sub> SO <sub>4</sub> ) 0.5M tartrate, pH 4.5 0.5M tartrate, pH 9 (waves not distinct) 1M NaOH; also anodic wave (3+ to 5+) at -0.45 0.5M tartrate plus 0.1M NaOH
5+	0.0; -0.257	6M HCl. First wave (5+ to 3+) starts at the oxidation potential of Hg; second wave is 3+ to 0.
5+ to 0	-0.35	1M HCl plus 4M KBr
<b>Arsenic</b> 3+ to 5+ 3+	-0.26 -0.8; -1.0 -0.7; -1.0	0.5M KOH (anodic wave); only suitable wave 0.1M HCl; ill-defined waves 0.5M H <sub>2</sub> SO <sub>4</sub> (or 1M HNO <sub>3</sub> )
<b>Barium</b> 2+ to 0	-1.94	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NI
<b>Bismuth</b> 3+ to 0	-0.025(15) -0.09 -0.29 -0.7 -1.0	1M HNO <sub>3</sub> (or 0.5M H <sub>2</sub> SO <sub>4</sub> ) 1M HCl 0.5M tartrate, pH 4.5 0.5M tartrate (pH 9), wave not well-developed 0.5M tartrate plus 0.1M NaOH, poor wave
<b>Bromine</b> 5+ to 1- 0 to 1- Br <sup>-</sup>	-1.75 0.13 0.0 0.1	0.1M alkali chlorides (or 0.1M NaOH) 0.05M H <sub>2</sub> SO <sub>4</sub> Wave (anodic) starts at zero; Hg <sub>2</sub> Br <sub>2</sub> forms Oxidation of Hg to form mercury(I) bromide
<b>Cadmium</b> 2+ to 0	-0.60 -0.64 -0.81	0.1M KCl, or 0.5M H <sub>2</sub> SO <sub>4</sub> , or 1M HNO <sub>3</sub> 0.5M tartrate at pH 4.5 or 9 1M NH <sub>4</sub> Cl plus 1M NH <sub>3</sub>
<b>Calcium</b> 2+ to 0	-2.22 -2.13	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NCl 0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NCl in 80% ethanol
<b>Cerium</b> 3+ to 0	-1.97	0.02M alkali sulfate
<b>Cesium</b> 1+ to 0	-2.05	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NOH in 50% ethanol
<b>Chlorine</b> Cl <sup>-</sup>	0.25	Oxidation of Hg to form Hg <sub>2</sub> Cl <sub>2</sub>
<b>Chromium</b> 6+ to 3+ 3+ to 0 3+ to 2+	-0.85 -0.35; -1.70 -0.95	CrO <sub>4</sub> <sup>2-</sup> to CrO <sub>2</sub> <sup>-</sup> in 0.1 to 1M NaOH 1M NH <sub>4</sub> Cl-NH <sub>3</sub> buffer (pH 8-9); 3+ to 2+ to 0 0.1M pyridine-0.1M pyridinium chloride

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

Element	$E_{1/2}$ , volts	Solvent system
2+ to 0	-1.54	1M KCl
2+ to 3+	-0.40	1M KCl (anodic wave)
<b>Cobalt</b>		
3+ to 0	-0.5; -1.3	1M NH <sub>4</sub> Cl plus 1M NH <sub>3</sub> ; 3+ to 2+ to 0
2+ to 0	-1.07	0.1M pyridine plus pyridinium chloride
	-1.03	Neutral 1M potassium thiocyanate
	-1.4	Co(H <sub>2</sub> O) <sub>6</sub> <sup>2+</sup> in noncomplexing systems
3+ to 2+	0.0	1M sodium oxalate in acetate buffer (pH 5); diffusion current measured between 0 and -0.1 V
<b>Copper</b>		
2+ to 0	0.04	0.1M KNO <sub>3</sub> , 0.1M NH <sub>4</sub> ClO <sub>4</sub> , or 1M Na <sub>2</sub> SO <sub>4</sub>
	-0.085	0.1M Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub> plus 0.2M Na acetate, pH 4.5
	-0.09	0.5M Na tartrate, pH 4.5
	-0.20	0.1M potassium oxalate, pH 5.7 to 10
	-0.22	0.5M potassium citrate, pH 7.5
	-0.4	0.5M Na tartrate plus 0.1M NaOH (pH 12)
	-0.568	0.1M KNO <sub>3</sub> plus 1M ethylenediamine
2+	0.04; -0.22	1M KCl; consecutive waves: 2+ to 1+ to 0
	-0.02; -0.39	0.1M KSCN; consecutive waves: 2+ to 1+ to 0
	0.05; -0.25	0.1M pyridine plus 0.1M pyridinium chloride; consecutive waves: 2+ to 1+ to 0
	-0.24; -0.50	1M NH <sub>4</sub> Cl plus 1M NH <sub>3</sub> ; consecutive waves
<b>Gallium</b>		
3+ to 0	-1.1	Not more than 0.001M HCl or wave masked by hydrogen wave which immediately follows
<b>Germanium</b>		
2+ to 0	-0.45	6M HCl; prior reduction with HPH <sub>2</sub> O <sub>2</sub> to 2+
<b>Gold</b>		
3+ to 1+	0	1M KCN; wave starts at 0 V
1+ to 0	-1.4	Au(CN) <sub>2</sub> <sup>-</sup> wave best for analytical purposes
<b>Indium</b>		
3+ to 0	-0.60	1M KCl In Na acetate, pH 3.9 to 4.2
<b>Iodine</b>		
IO <sub>4</sub> <sup>-</sup>	0.36	First wave at pH 0 (shifts to -0.08 at pH 12); second wave corresponds to iodate reduction
IO <sub>3</sub> <sup>-</sup>	-0.075	0.2M KNO <sub>3</sub> (shifts -0.13 V/pH unit increase)
	-0.305	0.1M hydrogen phthalate, pH 3.2
	-0.500	0.1M acetate plus 0.1M KCl, pH 4.9
	-0.650	0.1M citrate, pH 5.95
	-1.050	0.2M phosphate, pH 7.10
	-1.20	0.05M borax + 0.1M KCl, pH 9.2; or NaOH plus 0.1M KCl, pH 13.0
0 to 1-	0.0	Wave starts from zero in acid media; Hg <sub>2</sub> I <sub>2</sub> formed
1-	-0.1	Oxidation of Hg to form Hg <sub>2</sub> I <sub>2</sub>
<b>Iron</b>		
3+	-0.44; -1.52	1M (NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub> ; two waves; 3+ to 2+ to 0
	-0.17; -1.50	0.5M Na tartrate, pH 5.8; two waves; 3+ to 2+ to 0
	-0.9; -1.5	0.1 to 5M 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 -0.27 -0.28 -1.46(2)	0.1M EDTA plus 2M Na acetate, pH 6-7 0.2M Na oxalate, pH 7.9 or less 0.5M Na citrate, pH 6.5 1M $\text{NH}_4\text{ClO}_4$
2+ to 3+	-1.36 -0.28 -0.27 -0.17 -1.36	0.1M $\text{KHF}_2$ , pH 4 or less 0.5M Na citrate, pH 6.5 0.2M Na oxalate, pH 7.9 or less 0.5M Na tartrate, pH 5.8 0.1M $\text{KHF}_2$ , pH 4 or less
<b>Lead</b>		
2+ to 0	-0.405 -0.435 -0.49(1) -0.72 -0.75	1M $\text{HNO}_3$ 1M KCl (or HCl) 0.5M Na tartrate, pH 4.5 or 9 1M KCN 1M KOH or 0.5M Na tartrate plus 0.1M NaOH
<b>Lithium</b>		
1+ to 0	-2.31	0.1M $(\text{C}_2\text{H}_5)_4\text{NOH}$ in 50% ethanol
<b>Magnesium</b>		
2+ to 0	-2.2	0.1M $(\text{C}_2\text{H}_5)_4\text{NCl}$ (poorly defined wave)
<b>Manganese</b>		
2+ to 0	-1.65 -1.55 -1.33	1M $\text{NH}_4\text{Cl}$ plus 1M $\text{NH}_3$ 1M KCNS 1.5M KCN
<b>Molybdenum</b>		
6+	-0.26; -0.63	0.3M HCl, two waves: 6+ to 5+ to 3+
<b>Nickel</b>		
2+ to 0	-0.70 -0.78 -1.09 -1.1 -1.36	1M KSCN 1M KCl plus 0.5M pyridine 1M $\text{NH}_4\text{Cl}$ plus 1M $\text{NH}_3$ $\text{Ni}(\text{H}_2\text{O})_6^{2+}$ in $\text{NH}_4\text{ClO}_4$ or $\text{KNO}_3$ $\text{Ni}(\text{CN})_4^{2-}$ in 1M KCN (alkaline media)
<b>Niobium</b>		
5+ to 3+	-0.80(4)	1M $\text{HNO}_3$
<b>Nitrogen</b>		
Nitrate	-1.45	0.017M $\text{LaCl}_3$ (reduced to hydroxylamine)
$\text{HNO}_2$	-0.77	0.1M HCl
$\text{C}_2\text{N}_2$	-1.2; -1.55	0.1M Na acetate, two waves
Oxamic acid	-1.55	0.1M Na acetate
Cyanide	-0.45	0.1M NaOH; anodic wave starts at -0.45
Thiocyanate	0.18	Anodic wave; neutral or weakly alkaline medium
<b>Osmium</b>		
$\text{OsO}_4$	0.0; -0.41; -1.16	Sat'd $\text{Ca}(\text{OH})_2$ . Three waves: first starts at 0; second wave is $\text{OsO}_4^{2-}$ to Os(V); and third wave is Os(V) to Os(III)
<b>Oxygen</b>		
$\text{O}_2$	-0.05; -0.9	Buffer solutions of pH 1 to 10. Two waves: $\text{O}_2$ to $\text{H}_2\text{O}_2$ , and $\text{H}_2\text{O}_2$ to $\text{H}_2\text{O}$ . Second wave extends from -0.5 to -1.3
$\text{H}_2\text{O}_2$	-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
<b>Palladium</b>		
2+ to 0	-0.31	1M pyridine plus 1M KCl
	-0.64	0.1M ethylenediamine plus 1M KCl
	-0.72	1M NH <sub>4</sub> Cl plus 1M NH <sub>3</sub>
<b>Potassium</b>		
1+ to 0	-2.10	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NOH in 50% ethanol
<b>Rhenium</b>		
7+ to 4+	-0.44	2M HCl or (better) 4M HClO <sub>4</sub>
4+ to 3+	-0.51	ReCl <sub>6</sub> <sup>-</sup> ion in 1M HCl
<b>Rhodium</b>		
3+ to 2+	-0.41	1M pyridine plus 1M KCl
<b>Rubidium</b>		
1+ to 0	-1.99	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NOH in 50% ethanol
<b>Scandium</b>		
3+ to 0	-1.80	0.1M LiCl, KCl, or BaCl <sub>2</sub>
<b>Selenium</b>		
4+ to 2-	-1.44	1M NH <sub>4</sub> Cl plus NH <sub>3</sub> , 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 (0.01M NaOH)
<b>Silver</b>		
1+ to 0		Wave starts at oxidation potential of Hg
1+ to 0	-0.3	0.0014M KAg(CN) <sub>2</sub> without excess cyanide
<b>Sodium</b>		
1+ to 0	-2.07	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NOH in 50% ethanol
<b>Strontium</b>		
2+ to 0	-2.11	0.1M (C <sub>2</sub> H <sub>5</sub> ) <sub>4</sub> NI, water or 80% ethanol
<b>Sulfur</b>		
SO <sub>2</sub>	-0.38	1M HNO <sub>3</sub> (or other strong acid); 4+ to 2+
S <sub>2</sub> O <sub>4</sub> <sup>2-</sup>	-0.43	0.5M (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub> plus 1M NH <sub>3</sub> (anodic wave)
S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>	-0.15	1M strong acid; anodic mercury wave
0 to 2-	-0.50	90% methanol, 9.5% pyridine, 0.5% HCl (pH 6)
HS <sup>-</sup>	-0.76	0.1M NaOH (anodic mercury wave)
<b>Tellurium</b>		
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	0.1M NaOH
2- to 0	-0.72	1M HCl (true anodic reversible wave)
	-0.08	1M NaOH (same as above; intermediate values at pH 1 to 13)
<b>Thallium</b>		
3+ to 0	-0.48	1M KCl, KNO <sub>3</sub> , K <sub>2</sub> SO <sub>4</sub> , KOH, or NH <sub>3</sub>
<b>Tin</b>		
4+ to 2+	-0.25; -0.52	4M NH <sub>4</sub> Cl + 1M HCl; two waves: 4+ to 2+ to 0
2+ to 0	-0.59	0.5M tartrate, pH 4.3
	-1.22	1M NaOH (stannite ion to tin)
2+ to 4+	-0.28	0.5M Na tartrate, pH 4.3 (anodic wave)
	-0.73	1M NaOH (stannite ion to stannate ion)



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

Element	$E_{1/2}$ , volts	Solvent system
<b>Titanium</b> 4+ to 3+	-0.173 -1.22	0.1M $K_2C_2O_4$ plus 1M $H_2SO_4$ 0.4M tartrate, pH 6.5
<b>Tungsten</b> 6+	0.0; -0.64	6M HCl; two waves: first wave starts at zero and is W(VI) to W(V), the second wave is W(V) to W(III)
<b>Uranium</b> 6+	-0.180; -0.92	$UO_2^{2+}$ to $UO_2^+$ , then $U^{3+}$ in 0.02M HCL
<b>Vanadium</b> 5+ to 4+ to 2+	-0.97; -1.26	1M $NH_4Cl$ plus 1M $NH_3$ and 0.08M $Na_2SO_3$
4+ to 2+	-0.98	0.05M $H_2SO_4$
3+ to 2+	-0.55	0.5M $H_2SO_4$
4+ to 5+	-0.32	1M $NH_4Cl$ , 1M $NH_3$ , and 0.08M $Na_2SO_3$
4+ to 5+	0.76	0.05M $H_2SO_4$ ; anodic wave starting from zero
2+ to 3+	-0.55	0.5M $H_2SO_4$ ; anodic wave
<b>Zinc</b> 2+ to 0	-0.995 -1.01 -1.15 -1.23 -1.33 -1.53	0.1M KCl 0.1M KSCN 0.5M tartrate, pH 9 0.5M tartrate, pH 4.5 1M $NH_4Cl$ plus 1M $NH_3$ 1M 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  $\text{LiClO}_4$  or a tetraalkyl ammonium salt

B, acetic acid and an alkali acetate, often plus a tetraalkyl ammonium iodide

C, 0.05 to 0.175M 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 $\text{LiCl}$ +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	$\text{LiClO}_4$ in dimethylformamide	-0.16
<i>trans</i> -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	$E_{1/2}$
<i>Aromatic hydrocarbons (continued)</i>		
1,2-Benzanthracene	C	-2.03, -2.54
2,3-Benzanthracene	A	-0.54, -1.20
Benzene	A	-2.08
1,2-Benzo[ <i>a</i> ]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-Dimethylantracene	A	-0.65
2,3-Dimethylnaphthalene	A	-1.08, -1.34
9,10-Diphenylantracene	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
<i>trans</i> -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 ( <i>continued</i> )		
1,3,5-Trimethylbenzene	A	-1.50
	B	-1.90
Triphenylene	A	-1.46, -1.55
Triphenylmethane	C	-1.01, -1.68, -1.96
<i>o</i> -Xylene	A	-1.58, -2.04
<i>m</i> -Xylene	A	-1.58
<i>p</i> -Xylene	A	-1.56
Aldehydes		
Acetaldehyde	B, pH 6.8-13	-1.89
Benzaldehyde	McIlvaine buffer, pH 2.2	-0.96, -1.32
	pH 8.5	-0.40
Bromoacetaldehyde	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 <sub>4</sub> NI	-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
<i>o</i> -Methoxybenzaldehyde	Britton-Robinson buffer, pH 1.8	-1.02
	Britton-Robinson buffer, pH 6.8	-1.49
<i>p</i> -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
<i>m</i> -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 McIlvaine buffer, pH 5.0 McIlvaine buffer, pH 8.0	-0.99, -1.23 -1.20, -1.30 -1.32
Trichloroacetaldehyde	Ammonia buffer, pH 8.4 0.1 M KCl+50% EtOH	-1.35, -1.66 -1.55
Ketones		
Acetone	B, pH 9.3 C	-1.52 -2.46
Acetophenone	D+McIlvaine buffer, pH 4.9 D+McIlvaine buffer, pH 7.2 D+McIlvaine buffer, pH 1.3	-1.33 -1.58 -1.08
7 <i>H</i> -Benz[ <i>de</i> ]anthracen-7-one	0.1 N H <sub>2</sub> SO <sub>4</sub> +75% MeOH	-0.96
Benzil	D+McIlvaine buffer, pH 1.3 D+McIlvaine buffer, pH 4.9	-0.27 -0.50
Benzoin	D+McIlvaine buffer, pH 1.3 D+McIlvaine buffer, pH 8.6	-0.90 -1.49
Benzophenone	D+McIlvaine buffer, pH 1.3 D+McIlvaine buffer, pH 8.6	-0.94 -1.36
Benzoylacetone	Buffer, pH 2.6 Buffer, pH 5.3 and pH 7.6 Buffer, pH 9.7	-1.60 -1.68 -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 <sub>4</sub> Cl+50% EtOH	-1.55
D-Carvone	0.1 M Et <sub>4</sub> Ni+80% EtOH	-1.71
Chloroacetone	0.1 M LiCl	-1.18
Coumarin	McIlvaine buffer, pH 2.0 McIlvaine buffer, pH 5.0	-0.95 -1.11, -1.44
Cyclohexanone	C	-2.45
<i>cis</i> -Dibenzoylethylene	D, pH 1 D, pH 11	-0.30 -0.62, -1.65
<i>trans</i> -Dibenzoylethylene	D, pH 1 D, pH 11	-0.12 -0.57, -1.52
Dibenzoylmethane	D, pH 1.3 D, pH 11.3	-0.59 -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 <sub>2</sub> NOH+50% 2-PrOH, pH 6.1 Acetate buffer+Me <sub>2</sub> NOH+50% 2-PrOH, pH 9.6	-1.30 -1.51
Fluorescein	Acetate buffer, pH 2.0 Phthalate buffer, pH 5.0 Borate buffer, pH 10.1	-0.50 -0.65 -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	$E_{1/2}$
<i>Ketones (continued)</i>		
Girard derivatives of aliphatic ketones	pH 8.2	-1.52
<i>o</i> -Hydroxyacetophenone	D, pH 5	-1.36
<i>p</i> -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
$\alpha$ -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 <sub>4</sub> NI + 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
<i>Quinones</i>		
Anthraquinone	Acetate buffer + 40% dioxane, pH 5.6	-0.51
	Phosphate buffer + 40% dioxane, pH 7.9	-0.71
<i>o</i> -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 <sub>4</sub> +KClO <sub>4</sub> , pH 2.2	-1.13
4-Aminobenzenesulfonic acid	0.05 M Me <sub>4</sub> NI	-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	$E_{1/2}$
<i>Acids (continued)</i>		
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
<i>p</i> -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
<i>o</i> -Chlorophenol	pH 5.6	-0.63
<i>m</i> -Chlorophenol	pH 5.6	-0.73
<i>p</i> -Chlorophenol	pH 5.6	-0.65
<i>o</i> -Cresol	pH 5.6	-0.56
<i>m</i> -Cresol	pH 5.6	-0.61
<i>p</i> -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
<i>o</i> -Methoxyphenol	pH 5.6	-0.46
<i>m</i> -Methoxyphenol	pH 5.6	-0.62
<i>p</i> -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
<i>Halogen compounds</i>		
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
<i>p</i> -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
$\alpha$ -Chlorotoluene	C	-1.81
<i>p</i> -Chlorotoluene	A	-1.76
<i>N</i> -Chloro- <i>p</i> -toluenesulfonamide	0.5 M K <sub>2</sub> SO <sub>4</sub>	-0.13
9,10-Dibromoanthracene	A	-1.15, -1.47
<i>p</i> -Dibromobenzene	C	-2.10
1,2-Dibromobutane	D+1% Na <sub>2</sub> SO <sub>3</sub>	-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 ( <i>continued</i> )		
Dibromoethane	C	-1.48
<i>meso</i> -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
Tetraiodomethane	C	-0.45, -1.05, -1.46
Tribromomethane	C	-0.64, -1.47
$\alpha,\alpha,\alpha$ -Trichlorotoluene	C	-0.68, -1.65, -2.00
Nitro and nitroso compounds		
1,2-Dinitrobenzene	Phthalate buffer, pH 2.5 Borate buffer, pH 9.2	-0.12, -0.32, -1.26 -0.38, -0.74
1,3-Dinitrobenzene	Phthalate buffer, pH 2.5 Borate buffer, pH 9.2	-0.17, -0.29 -0.46, -0.68
1,4-Dinitrobenzene	Phthalate buffer, pH 2.5 Borate buffer, pH 9.2	-0.12, -0.33 -0.35, -0.80
Methyl nitrobenzoates	Buffer+10% EtOH, pH 2.0	-0.20 to -0.25 -0.68 to -0.74
<i>p</i> -Nitroacetophenone	Britton-Robinson buffer, pH 2.2 Britton-Robinson buffer, pH 10.0	-0.16, -0.61, -1.09 -0.51, -1.40, -1.73
<i>o</i> -Nitroaniline	0.03 M LiCl+0.02 M benzoic acid in EtOH	-0.88
<i>m</i> -Nitroaniline	Britton-Robinson buffer, pH 4.3 Britton-Robinson buffer, pH 7.2 Britton-Robinson buffer, pH 9.2	-0.3, -0.8 -0.5 -0.7
<i>p</i> -Nitroaniline	pH 2.0 Acetate buffer, pH 4.6	-0.36 -0.5
<i>o</i> -Nitroanisole	Buffer+10% EtOH, pH 2.0	-0.29, -0.58
<i>p</i> -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 Phthalate buffer, pH 2.5 Borate buffer, pH 9.2	-0.16, -0.76 -0.30 -0.70
Nitroresols	Britton-Robinson buffer, pH 2.2 Britton-Robinson buffer, pH 4.5 Britton-Robinson buffer, pH 8.0	-0.2 to -0.3 -0.4 to -0.5 -0.6
Nitroethane	Britton-Robinson buffer+30% MeOH, pH 1.8 Britton-Robinson buffer+30% MeOH, pH 4.6	-0.7 -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
<i>o</i> -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
<i>m</i> -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
<i>p</i> -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
	Britton-Robinson buffer+30% MeOH, pH 1.8	-0.73
1-Nitropropane	Britton-Robinson buffer+30% MeOH, pH 8.6	-0.88
	Britton-Robinson buffer+30% MeOH, pH 8.0	-0.95
	McIlvaine buffer, pH 2.1	-0.53
2-Nitropropane	McIlvaine buffer, pH 5.1	-0.81
	McIlvaine buffer, pH 6.0	-0.03
Nitrosobenzene	McIlvaine buffer, pH 8.0	-0.14
	D+buffer, pH 4.0	+0.02
1-Nitroso-2-naphthol	D+buffer, pH 7.0	-0.20
	D+buffer, pH 9.0	-0.31
	pH 2.0	-0.84
<i>N</i> -Nitrosophenylhydroxylamine	Phthalate buffer, pH 2.5	-0.35, -0.66
<i>o</i> -Nitrotoluene	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)		
<i>m</i> -Nitrotoluene (also <i>p</i> -nitrotoluene)	Phthalate buffer, pH 2.5 Phthalate buffer, pH 7.4	-0.30, -0.53 -0.58, -1.06
Tetranitromethane	pH 12.0	-0.41
1,3,5-Trinitrobenzene	Phthalate buffer, pH 4.1 Borate buffer, pH 9.2	-0.20, -0.29, -0.34 -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 Britton-Robinson buffer, pH 5.8	-0.96 -1.38, -1.70
2-Hydroxyphenazine	Britton-Robinson buffer, pH 4.0	-0.24
8-Hydroxyquinoline	B, pH 5.0 Phosphate buffer, pH 8.0	-1.12 -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 B, pH 9.3	-1.10 -1.48, -1.94
Pyridine-3-carboxylic acid	0.1 M HCl	-1.08
Pyridine-4-carboxylic acid	Britton-Robinson buffer, pH 6.1 pH 9.0	-1.14 -1.39, -1.68
Pyrimidine	Citrate buffer, pH 3.6 Ammonia buffer, pH 9.2	-0.92, -1.24 -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 D, pH 7.0	-0.20 -0.50
Azoxybenzene	Buffer+20% EtOH, pH 6.3	-0.30
Benzoin 1-oxime	Buffer, pH 2.0 Buffer, pH 5.6 Buffer, pH 8.2	-0.88 -1.08 -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 Britton-Robinson buffer, pH 9.2	-1.42 -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 ( <i>continued</i> )		
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
	Phosphate buffer, pH 5.4	-1.02
Salicylaldoxime	Borate buffer, pH 9.3	-0.26
Thiosemicarbazide	0.1 M sulfuric acid	+0.02
Thiourea		
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
	Phosphate buffer+1% EtOH, pH 7.0	-0.51
Methyl orange	D, pH 7.6	-1.7
Morin	Britton-Robinson buffer, pH 2.0	-0.21
	Britton-Robinson buffer, pH 7.0	-0.57
Neutral red		
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  $mho \cdot cm^2 \cdot equiv^{-1}$ .

Ion	Temperature, °C		
	0	18	25
<b>Inorganic cations</b>			
Ag <sup>+</sup>	33	54.5	61.9
Al <sup>3+</sup>	29		61
Ba <sup>2+</sup>	33.6	54.3	63.9
Be <sup>2+</sup>			45
Ca <sup>2+</sup>	30.8	51	59.5
Cd <sup>2+</sup>	28	45.1	54
Ce <sup>3+</sup>			70
Co <sup>2+</sup>	28	45	53
Co(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup>			100
Co(ethylenediamine) <sub>3</sub> <sup>3+</sup>			74.7
Cr <sup>3+</sup>			67
Cs <sup>+</sup>	44	68	77.3
Cu <sup>2+</sup>	28	45.3	56.6
D <sup>+</sup> (deuterium)		213.7	
Dy <sup>3+</sup>			65.7
Er <sup>3+</sup>			66.0
Eu <sup>3+</sup>			67.9
Fe <sup>2+</sup>	28	45.3	53.5
Fe <sup>3+</sup>			69
Gd <sup>3+</sup>			67.4
H <sup>+</sup>	224.1	315.8	350.1
Hg <sub>2</sub> <sup>2+</sup>			68.7
Hg <sup>2+</sup>			63.6
Ho <sup>3+</sup>			66.3
K <sup>+</sup>	40.3	64.6	73.5
La <sup>3+</sup>	35.0	59.2	69.6
Li <sup>+</sup>	19.1	33.4	38.69
Mg <sup>2+</sup>	28.5	46	53.06
Mn <sup>2+</sup>	27	44.5	53.5
NH <sub>4</sub> <sup>+</sup>	40.3	64	73.7
N <sub>2</sub> H <sub>5</sub> <sup>+</sup> (hydrazinium 1 +)			59
Na <sup>+</sup>	25.85	43.5	50.11
Nd <sup>3+</sup>			69.6
Ni <sup>2+</sup>	28	45	50
Pb <sup>2+</sup>	37.5	60.5	71
Pr <sup>3+</sup>			69.6
Ra <sup>2+</sup>	33	56.6	66.8
Rb <sup>+</sup>	43.5	67.5	77.8
Sc <sup>3+</sup>			64.7
Sm <sup>3+</sup>			68.5
Sr <sup>2+</sup>	31	51	59.46
Tl <sup>+</sup>	43.3	66	74.9
Tm <sup>3+</sup>			65.5
UO <sub>2</sub> <sup>2+</sup>			32
Y <sup>3+</sup>			62
Yb <sup>3+</sup>			65.2
Zn <sup>2+</sup>	28	45.0	52.8

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

Ion	Temperature, °C		
	0	18	25
<b>Inorganic anions</b>			
Au(CN) <sub>2</sub> <sup>-</sup>			50
Au(CN) <sub>4</sub> <sup>-</sup>			36
B(C <sub>6</sub> H <sub>5</sub> ) <sub>4</sub> <sup>-</sup>			21
Br <sup>-</sup>	43.1	67.6	78.1
Br <sub>3</sub> <sup>-</sup>			43
BrO <sub>3</sub> <sup>-</sup>	31.0	49.0	55.7
Cl <sup>-</sup>	41.4	65.5	76.31
ClO <sub>2</sub> <sup>-</sup>			52
ClO <sub>3</sub> <sup>-</sup>	36	55.0	64.6
ClO <sub>4</sub> <sup>-</sup>	37.3	59.1	67.3
CN <sup>-</sup>			78
CO <sub>3</sub> <sup>2+</sup>	36	60.5	69.3
Co(CN) <sub>6</sub> <sup>3-</sup>			98.9
CrO <sub>4</sub> <sup>2-</sup>	42	72	85
F <sup>-</sup>		46.6	55.4
Fe(CN) <sub>6</sub> <sup>4-</sup>			110.4
Fe(CN) <sub>6</sub> <sup>3-</sup>			100.9
H <sub>2</sub> AsO <sub>4</sub> <sup>-</sup>			34
HCO <sub>3</sub> <sup>-</sup>			44.5
HF <sub>2</sub> <sup>-</sup>			75
HPO <sub>4</sub> <sup>2-</sup>			33
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>		28	33
HS <sup>-</sup>	40	57	65
HSO <sub>3</sub> <sup>-</sup>	27		50
HSO <sub>4</sub> <sup>-</sup>			50
H <sub>2</sub> SbO <sub>4</sub> <sup>-</sup>			31
I <sup>-</sup>	42.0	66.5	76.9
IO <sub>3</sub> <sup>-</sup>	21.0	33.9	40.5
IO <sub>4</sub> <sup>-</sup>		49	54.5
MnO <sub>4</sub> <sup>-</sup>	36	53	61.3
MoO <sub>4</sub> <sup>2-</sup>			74.5
N <sub>3</sub> <sup>-</sup>			69.5
N(CN) <sub>2</sub> <sup>-</sup>			54.5
NO <sub>2</sub> <sup>-</sup>	44	59	71.8
NO <sub>3</sub> <sup>-</sup>	40.2	61.7	71.42
NH <sub>2</sub> SO <sub>3</sub> <sup>-</sup> (sulfamate)			48.6
OCN <sup>-</sup> (cyanate)		54.8	64.6
OH <sup>-</sup>	117.8	175.8	198
PF <sub>6</sub> <sup>-</sup>			56.9
PO <sub>3</sub> F <sup>2-</sup>			63.3
PO <sub>3</sub> <sup>3-</sup>			69.0
P <sub>2</sub> O <sub>7</sub> <sup>4-</sup>			96
P <sub>3</sub> O <sub>9</sub> <sup>3-</sup>			83.6
P <sub>3</sub> O <sub>10</sub> <sup>5-</sup>			109
ReO <sub>4</sub> <sup>-</sup>		46.5	54.9
SCN <sup>-</sup> (thiocyanate)	41.7	56.6	66.5
SeCN <sup>-</sup>			64.7
SeO <sub>4</sub> <sup>2-</sup>		65	75.7
SO <sub>3</sub> <sup>2-</sup>			79.9

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

Ion	Temperature, °C		
	0	18	25
SO <sub>4</sub> <sup>2-</sup>	41	68.3	80.0
S <sub>2</sub> O <sub>3</sub> <sup>2-</sup>			85.0
S <sub>2</sub> O <sub>4</sub> <sup>2-</sup>	34		66.5
S <sub>2</sub> O <sub>6</sub> <sup>2-</sup>			93
S <sub>2</sub> O <sub>8</sub> <sup>2-</sup>			86
WO <sub>4</sub> <sup>2-</sup>	35	59	69.4
<b>Organic cations</b>			
Decylpyridinium <sup>+</sup>			29.5
Diethylammonium <sup>+</sup>			42.0
Dimethylammonium <sup>+</sup>			51.5
Dipropylammonium <sup>+</sup>			30.1
Dodecylammonium <sup>+</sup>			23.8
Ethylammonium <sup>+</sup>			47.2
Ethyltrimethylammonium <sup>+</sup>			40.5
Isobutylammonium <sup>+</sup>			38.0
Methylammonium <sup>+</sup>			58.3
Piperidinium <sup>+</sup>			37.2
Propylammonium <sup>+</sup>			40.8
Tetrabutylammonium <sup>+</sup>			19.5
Tetraethylammonium <sup>+</sup>			32.6
Tetramethylammonium <sup>+</sup>			44.9
Tetrapropylammonium <sup>+</sup>			23.5
Triethylsulfonium <sup>+</sup>			36.1
Trimethylammonium <sup>+</sup>			47.2
Trimethylsulfonium <sup>+</sup>			51.4
Tripropylammonium <sup>+</sup>			26.1
<b>Organic anions</b>			
Acetate <sup>-</sup>	20	34	41
Benzoate <sup>-</sup>			32.4
Bromoacetate <sup>-</sup>			39.2
Bromobenzoate <sup>-</sup>			30
Butanoate <sup>-</sup>			32.6
Chloroacetate <sup>-</sup>			42.2
<i>m</i> -Chlorobenzoate <sup>-</sup>			31
<i>o</i> -Chlorobenzoate <sup>-</sup>			30.5
Citrate(3 <sup>-</sup> )			70.2
Crotonate <sup>-</sup>			33.2
Cyanoacetate <sup>-</sup>			43.4
Cyclohexanecarboxylate <sup>-</sup>			28.7
Cyclopropane-1,3-dicarboxylate <sup>2-</sup>			53.4
Decylsulfonate <sup>-</sup>			26
Dichloroacetate <sup>-</sup>			38.3
Diethylbarbiturate(2 <sup>-</sup> )			26.3
Dihydrogencitrate <sup>-</sup>			30
Dimethylmalonate(2 <sup>-</sup> )			49.4
3,5-Dinitrobenzoate <sup>-</sup>			28.3
Dodecylsulfonate <sup>-</sup>			24
Ethylmalonate <sup>-</sup>			49.3
Ethylsulfonate <sup>-</sup>			39.6

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

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

**TABLE 8.33** Standard Solutions for Calibrating Conductivity Vessels

The values of conductivity  $\kappa$  are corrected for the conductivity of the water used. The cell constant  $\theta$  of a conductivity cell can be obtained from the equation

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

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

Grams KCl per Kilogram Solution (in vacuo)	Conductivity in $\text{ohm}^{-1} \cdot \text{cm}^{-1}$ at		
	0°C	18°C	25°C
71.135 2	0.065 14 <sub>4</sub>	0.097 79 <sub>0</sub>	0.111 28 <sub>7</sub>
7.419 13	0.007 134 <sub>4</sub>	0.011 161 <sub>2</sub>	0.012 849 <sub>7</sub>
0.745 263*	0.000 773 2 <sub>6</sub>	0.001 219 9 <sub>2</sub>	0.001 408 0 <sub>8</sub>

\* 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)<sup>-1</sup> cm<sup>-1</sup>.



TABLE 8.34 Electrical Conductivity of Various Pure Liquids

Liquid	Temp. °C	mhos/cm or $\text{ohm}^{-1} \cdot \text{cm}^{-1}$	Liquid	Temp. °C	mhos/cm or $\text{ohm}^{-1} \cdot \text{cm}^{-1}$
Acetaldehyde	15	$1.7 \times 10^{-6}$	Epichlorohydrin	25	$3.4 \times 10^{-8}$
Acetamide	100	$<4.3 \times 10^{-5}$	Ethyl acetate	25	$<1 \times 10^{-9}$
Acetic acid	0	$5 \times 10^{-9}$	Ethyl acetoacetate	25	$4 \times 10^{-8}$
	25	$1.12 \times 10^{-8}$	Ethyl alcohol	25	$1.35 \times 10^{-9}$
Acetic anhydride	0	$1 \times 10^{-6}$	Ethylamine	0	$4 \times 10^{-7}$
	25	$4.8 \times 10^{-7}$	Ethyl benzoate	25	$<1 \times 10^{-9}$
Acetone	18	$2 \times 10^{-8}$	Ethyl bromide	25	$<2 \times 10^{-8}$
	25	$6 \times 10^{-8}$	Ethylene bromide	19	$<2 \times 10^{-10}$
Acetonitrile	20	$7 \times 10^{-6}$	Ethylene chloride	25	$3 \times 10^{-8}$
Acetophenone	25	$6 \times 10^{-9}$	Ethyl ether	25	$<4 \times 10^{-13}$
Acetyl bromide	25	$2.4 \times 10^{-6}$	Ethylidene chloride	25	$<1.7 \times 10^{-8}$
Acetyl chloride	25	$4 \times 10^{-7}$	Ethyl iodide	25	$<2 \times 10^{-8}$
Alizarin	233	$1.45 \times 10^{-6}$ (?)	Ethyl isothiocyanate	25	$1.26 \times 10^{-7}$
Allyl alcohol	25	$7 \times 10^{-6}$	Ethyl nitrate	25	$5.3 \times 10^{-7}$
Ammonia	-79	$1.3 \times 10^{-7}$	Ethyl thiocyanate	25	$1.2 \times 10^{-6}$
Aniline	25	$2.4 \times 10^{-8}$	Eugenol	25	$<1.7 \times 10^{-8}$
Anthracene	230	$3 \times 10^{-10}$			
Arsenic tribromide	35	$1.5 \times 10^{-6}$	Formamide	25	$4 \times 10^{-6}$
Arsenic trichloride	25	$1.2 \times 10^{-6}$	Formic acid	18	$5.6 \times 10^{-5}$
				25	$6.4 \times 10^{-5}$
Benzaldehyde	25	$1.5 \times 10^{-7}$	Furfural	25	$1.5 \times 10^{-6}$
Benzene	...	$7.6 \times 10^{-8}$			
Benzoic acid	125	$3 \times 10^{-9}$	Gallium	30	36,800
Benzonitrile	25	$5 \times 10^{-8}$	Glycerol	25	$6.4 \times 10^{-8}$
Benzyl alcohol	25	$1.8 \times 10^{-6}$	Glycol	25	$3 \times 10^{-7}$
Benzylamine	25	$<1.7 \times 10^{-8}$	Guaiacol	25	$2.8 \times 10^{-7}$
Benzyl benzoate	25	$<1 \times 10^{-9}$			
Bromine	17.2	$1.3 \times 10^{-13}$	Heptane	...	$<1 \times 10^{-13}$
Bromobenzene	25	$<2 \times 10^{-11}$	Hexane	18	$<1 \times 10^{-18}$
Bromoform	25	$<2 \times 10^{-8}$	Hydrogen bromide	-80	$8 \times 10^{-9}$
<i>iso</i> -Butyl alcohol	25	$8 \times 10^{-8}$	Hydrogen chloride	-96	$1 \times 10^{-8}$
			Hydrogen cyanide	0	$3.3 \times 10^{-6}$
Capronitrile	25	$3.7 \times 10^{-6}$	Hydrogen iodide	B.P.	$2 \times 10^{-7}$
Carbon disulfide	1	$7.8 \times 10^{-18}$	Hydrogen sulfide	B.P.	$1 \times 10^{-11}$
Carbon tetrachloride	18	$4 \times 10^{-18}$			
Chlorine	-70	$<1 \times 10^{-16}$	Iodine	110	$1.3 \times 10^{-10}$
Chloroacetic acid	60	$1.4 \times 10^{-6}$			
<i>m</i> -Chloroaniline	25	$5 \times 10^{-8}$	Kerosene	25	$<1.7 \times 10^{-8}$
Chloroform	25	$<2 \times 10^{-8}$			
Chlorohydrin	25	$5 \times 10^{-7}$	Mercury	0	10,629.6
<i>m</i> -Cresol	25	$<1.7 \times 10^{-8}$	Methyl acetate	25	$3.4 \times 10^{-6}$
Cyanogen	...	$<7 \times 10^{-9}$	Methyl alcohol	18	$4.4 \times 10^{-7}$
Cymene	25	$<2 \times 10^{-8}$	Methyl ethyl ketone	25	$1 \times 10^{-7}$
			Methyl iodide	25	$<2 \times 10^{-8}$
Dichloroacetic acid	25	$7 \times 10^{-8}$	Methyl nitrate	25	$4.5 \times 10^{-6}$
Dichlorohydrin	25	$1.2 \times 10^{-5}$	Methyl thiocyanate	25	$1.5 \times 10^{-6}$
Diethylamine	-33.5	$2.2 \times 10^{-9}$			
Diethyl carbonate	25	$1.7 \times 10^{-8}$	Naphthalene	82	$4 \times 10^{-10}$
Diethyl oxalate	25	$7.6 \times 10^{-7}$	Nitrobenzene	0	$5 \times 10^{-9}$
Diethyl sulfate	25	$2.6 \times 10^{-7}$	Nitromethane	18	$6 \times 10^{-7}$
Dimethyl sulfate	0	$1.6 \times 10^{-7}$	<i>o</i> - or <i>m</i> -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 $\text{ohm}^{-1} \cdot \text{cm}^{-1}$	Liquid	Temp. °C	mhos/cm or $\text{ohm}^{-1} \cdot \text{cm}^{-1}$
Oleic acid	15	$<2 \times 10^{-10}$	Salicylaldehyde	25	$1.6 \times 10^{-7}$
Pentane	19.5	$<2 \times 10^{-10}$	Stearic acid	80	$<4 \times 10^{-13}$
Petroleum	...	$3 \times 10^{-13}$	Sulfonyl chloride, SOCl <sub>2</sub>	25	$2 \times 10^{-6}$
Phenetole	25	$<1.7 \times 10^{-8}$	Sulfur	115	$1 \times 10^{-12}$
Phenol	25	$<1.7 \times 10^{-8}$		130	$5 \times 10^{-12}$
Phenyl isothiocyanate	25	$1.4 \times 10^{-6}$		440	$1.2 \times 10^{-7}$
Phosgene	25	$7 \times 10^{-9}$	Sulfur dioxide	35	$1.5 \times 10^{-8}$
Phosphorus	25	$4 \times 10^{-7}$	Sulfuric acid	25	$1 \times 10^{-2}$
Phosphorus oxychloride	25	$2.2 \times 10^{-6}$	Sulfuryl chloride, SO <sub>2</sub> Cl <sub>2</sub>	25	$3 \times 10^{-8}$
Pinene	23	$<2 \times 10^{-10}$			
Piperidine	25	$<2 \times 10^{-7}$	Toluene	...	$<1 \times 10^{-14}$
Propionaldehyde	25	$8.5 \times 10^{-7}$	<i>o</i> -Toluidine	25	$<2 \times 10^{-6}$
Propionic acid	25	$<1 \times 10^{-9}$	<i>p</i> -Toluidine	100	$6.2 \times 10^{-8}$
Propionitrile	25	$<1 \times 10^{-7}$	Trichloroacetic acid	25	$3 \times 10^{-9}$
<i>n</i> -Propyl alcohol	18	$5 \times 10^{-8}$	Trimethylamine	-33.5	$2.2 \times 10^{-10}$
	25	$2 \times 10^{-8}$	Turpentine	...	$2 \times 10^{-13}$
<i>iso</i> -Propyl alcohol	25	$3.5 \times 10^{-6}$			
<i>n</i> -Propyl bromide	25	$<2 \times 10^{-8}$	<i>iso</i> -Valeric acid	80	$<4 \times 10^{-13}$
Pyridine	18	$5.3 \times 10^{-8}$	Water	18	$4 \times 10^{-8}$
Quinoline	25	$2.2 \times 10^{-8}$	Xylene	...	$<1 \times 10^{-15}$

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

The unit of  $\Lambda$  in the table is  $\Omega^{-1} \cdot \text{cm}^{-2} \cdot \text{equiv}^{-1}$ . 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 <sub>3</sub>	113.2	110.0	107.8	99.5	94.3	77.8	67.8	56.0	48.2	42.1	37.2
½Ag <sub>2</sub> SO <sub>4</sub>	116.3	108.4	102.9								
½AlBr <sub>3</sub> (25°)	132	124	119	103	97						
½AlCl <sub>3</sub>	121.1	105.0	93.8			65.0	56.2	44.2	34.7	27.2	
½AlI <sub>3</sub> (25°)	131	124	119	108							
½Al(NO <sub>3</sub> ) <sub>3</sub> (25°)	123	115	110	94	88						
⅙Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> (25°)	107.2	76.8	60.6								
½Ba(OAc) <sub>2</sub>	85.0	80.4	77.1	65.7	60.2	43.8	34.3				
½Ba(BrO <sub>3</sub> ) <sub>2</sub> (25°)	113.6	106.8	102.7								
½BaCl <sub>2</sub>	115.6	112.3	106.7	96.0	90.8	77.3	70.1	60.3	52.3		
½Ba(NO <sub>3</sub> ) <sub>2</sub>	111.7	105.3	101.0	86.8	78.9	56.6	48.4		29.8	23.4	
½Ba(OH) <sub>2</sub>	216	213	207	191	180						
Butyric acid						1.66	0.98	0.46	0.26	0.18	0.11
½Ca(OAc) <sub>2</sub>	79.6	75.0	71.9	60.3	54.0	36.3	26.3				
½CaCl <sub>2</sub>	112.0	106.7	103.4	93.3	88.2	74.9	67.5	58.3	49.7	42.4	35.6
½Ca(NO <sub>3</sub> ) <sub>2</sub>	108.5	103.0	99.5	88.4	82.5	65.7	55.9	43.5	35.5	26.0	21.5
½Ca(OH) <sub>2</sub>		233	226								
½CaSO <sub>4</sub>	104.3	86.3	77.4								
½CdBr <sub>2</sub>		86.5	76.3	53.2	44.6	25.3	18.3	12.5	9.1	6.8	5.3
½CdCl <sub>2</sub>		91	83	59	50	30.8	22.4	14.4	9.9	7.1	5.4
½CdI <sub>2</sub>		76.7	65.6	40.1	31.0	18.3	15.4	12.3	9.7	8.0	
½Cd(NO <sub>3</sub> ) <sub>2</sub>		100	96	86.4	80.8	63.9	54.5	41.0	31.4	23.7	17.6
½CdSO <sub>4</sub>	97.7	79.7	70.3	49.6	42.2	28.7	23.6	17.7	14.0	11.0	8.35
½CeCl <sub>3</sub> (25°)	137.4		122.1		99.0						
⅙Ce <sub>2</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>3</sub> (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				
½CoCl <sub>2</sub>		99.3	95.6	82.3	75.0	51.5	45.3	40.3	35.4	30.5	26.4
½CrCl <sub>3</sub>						68.6	56.8	44.8	35.2		

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

Electrolyte	Concentration, <i>N</i>										
	0.001	0.005	0.01	0.05	0.1	0.5	1.0	2.0	3.0	4.0	5.0
$\frac{1}{2}\text{CrO}_3(\text{H}_2\text{CrO}_4)$ (25°)	201	195	193	191	186						
CsCl	130.7	127.5	125.2		113.5	104.3	100.3	95.7	85.1		
$\frac{1}{2}\text{Cu}(\text{OAc})_2$ (25°)	55.7	50.6	47.2	34.9	28.4						
$\frac{1}{2}\text{CuCl}_2$								41.2	31.5	24.5	19.1
$\frac{1}{2}\text{Cu}(\text{NO}_3)_2$ (15°)	107.9	97.1	93.7	83.7	78.2	67.5	56.8	45.4	35.3	27.8	21.4
$\frac{1}{2}\text{CuSO}_4$	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
$\frac{1}{2}\text{FeCl}_2$ (25°)	131	125	120	103	93						
$\frac{1}{3}\text{FeCl}_3$						66.5	52.9	37.6	28.1	20.5	15.9
$\frac{1}{2}\text{FeSO}_4$	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
$\text{H}_3\text{AsO}_4$ (1 <i>M</i> ) (25°)	308.2	230.0	187.0	103.4	80.4						
$\text{H}_3\text{BO}_3$	13.5										
HBr					356	306	282	243	214	179	
$\text{HBrO}_3$ (25°)	401	387	373	272	156						
HCl	377	373	370	360	351	327	301		215		152.2
$\text{HClO}_3$					343	317	292	247	207		
$\text{HClO}_4$ (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	
$\text{HIO}_3$	343.3	332.8	323.9		253	175	141	106	87	71	
$\text{HNO}_3$	375	371	368	357	350	324	310		220		156
$\text{H}_3\text{PO}_4$ (1 <i>M</i> )	318	279	255				66		53.1		51.3
$\text{HSCN}$ (25°)	399	394	390	377	370						
$\frac{1}{2}\text{H}_2\text{SO}_4$	361	330	308	253	225	205	198		166.8		135.0
$\frac{1}{2}\text{HgCl}_2$				1.85	1.23						
$\frac{1}{3}\text{InBr}_3$					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	
$\text{KBrO}_3$	109.9	106.9	104.7	97.3	93.0						
$\frac{1}{3}\text{K}_3\text{citrate}$		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 <sub>3</sub>	116.9	113.6	111.6	103.7	99.2	85.3					
KClO <sub>4</sub> (25°)	137.9	134.2	131.5	121.6	115.2						
KCN (15°)						104.2	99.7				
½K <sub>2</sub> CO <sub>3</sub>	133.0	121.6	115.5	100.7	94.1	77.8	70.7	65.0	55.6	49.2	42.9
½K <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	122.4	116.7	112.5	100.8	94.9	80.4	73.7				
½K <sub>2</sub> CrO <sub>4</sub>					100.5	86.4	79.5	72.0	59.9		
½K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>					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 <sub>3</sub> [Fe(CN) <sub>6</sub> ]	163.1	150.7									
¼K <sub>4</sub> [Fe(CN) <sub>6</sub> ]	167.2	146.1	134.8	107.7	97.9						
KHCO <sub>3</sub> (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 <sub>4</sub>						21.0	18.4	15.2			
KH <sub>2</sub> PO <sub>4</sub> (1 M) (25°)	107.1	100.8	98.0	90.7	85.6	60.0 <sup>18</sup>	45.8 <sup>18</sup>				
KI	128.2	125.3	123.4	117.3	114.0	106.2	103.6	101.3	96.4	89.0	81.2
KIO <sub>3</sub>	96.0	93.2	91.2	84.1	79.7						
KIO <sub>4</sub> (25°)	124.9	121.2	118.5	106.7	98.1						
KMnO <sub>4</sub> (25°)	133.3		126.5		113						
KNO <sub>3</sub>	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 <sub>4</sub> (25°)	125.1	121.3	118.5	106.4	97.4						
½K <sub>2</sub> S							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 <sub>2</sub> SO <sub>4</sub>	126.9	120.3	115.8	101.9	94.9	78.5	71.6				
½LaCl <sub>3</sub> (25°)	137.0	127.5	121.8	106.2	99.1						
⅓La(NO <sub>3</sub> ) <sub>3</sub>				86.1	72.1	65.4	54.0	39.1	28.5	19.9	
⅙La <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>				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 <sub>4</sub> (25°)	103.4	100.6	98.6	92.2	88.6						
½Li <sub>2</sub> CO <sub>3</sub>				64.2	59.1						
LiI						75.3	69.2	61.0			
LiIO <sub>3</sub>	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, <i>N</i>										
	0.001	0.005	0.01	0.05	0.1	0.5	1.0	2.0	3.0	4.0	5.0
LiNO <sub>3</sub>	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 <sub>2</sub> SO <sub>4</sub>	96.4		86.9	74.7	68.2	50.5	41.3	30.7	23.3	18.1	13.9
½MgCl <sub>2</sub>	106.4	101.3	98.1	88.5	83.4	69.6	61.5	52.3	43.3	35.0	28.0
½Mg(NO <sub>3</sub> ) <sub>2</sub>	102.6	97.7	94.7	85.3	80.5	67.0	59.0	47.0	39.8		
½MgSO <sub>4</sub>	99.8	84.5	76.2	56.9	49.7	35.4	28.9	23.0	17.3	12.9	9.3
½MnCl <sub>2</sub>					86.0	68.5	61.0	48.5	38.8	30.2	23.0
½MnSO <sub>4</sub>						27.6	24.4	18.3	14.0	10.5	7.3
NH <sub>3</sub> (aq)	28.0	13.2	9.6	4.6	3.3	1.35	0.89		0.36		0.20
NH <sub>4</sub> OAc		92.9	91.4	84.9		60.5	54.7	42.9	34.0	26.5	
NH <sub>4</sub> Cl	127.3	124.3	122.1	115.2	110.7	101.4	97.0	92.1	88.2	85.0	80.7
NH <sub>4</sub> F					90.1	74.5	65.7	55.3	47.9	42.2	
NH <sub>4</sub> I				118.0	115.0	106.0	103.1	100.0		91.4	84.5
NH <sub>4</sub> NO <sub>3</sub>	124.5		118.0	110.0	106.6	94.5	88.8	85.1		71.9	47.6
NH <sub>4</sub> SCN					104.3	94.0	89.9	84.7	79.2	74.0	
½(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>		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 <sub>3</sub>						61.8	54.5	44.1			
Na <i>n</i> -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 <sub>4</sub>	114.9 <sup>25</sup>	111.7 <sup>25</sup>	109.6 <sup>25</sup>	102.4 <sup>25</sup>	98.4 <sup>25</sup>	71.7	65.0	55.1	46.0	38.8	
½Na <sub>2</sub> CO <sub>3</sub>	112	102.5	96.2	80.3	72.9	54.5	45.5	34.5	27.2		
½Na <sub>2</sub> CrO <sub>4</sub>					82.5	66.4	57.7	46.6	38.3	31.1	
½Na <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> (25°)		103		98.3	94.9						
NaF	87.8	85.2	83.5	77.0	73.1	60.0	51.9				
¼Na <sub>4</sub> [Fe(CN) <sub>6</sub> ] (25°)		129.6	120.0	97.0	88.2						
Na formate	88.6					61.4	53.7	43.1	34.8	28.2	
NaHCO <sub>3</sub> (25°)	93.5	90.5	88.4	80.6	76.0						
⅓Na <sub>3</sub> HPO <sub>4</sub>	58.4		54.0		44.0	33.5	28.0				
NaH <sub>2</sub> PO <sub>4</sub>	67.9	65.8	64.4	57.8	54.1						
¼Na <sub>3</sub> H <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	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 <sub>3</sub>	75.2	72.6	70.9	64.4	60.5						
½Na <sub>2</sub> MoO <sub>4</sub>	120.8	113	110								
NaN <sub>3</sub> (25°)	117.1	113.8	110.5	101.3	95.7		68.0				
NaNO <sub>2</sub> (25°)							75.9	63.1	53.6		39.7
NaNO <sub>3</sub>	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 <sub>3</sub> PO <sub>4</sub>	125	122	119	91							
Na propionate (25°)	83.5	80.9	79.1								
½Na <sub>2</sub> S						117.0	104.3	85.0	71.0	59.0	47.2
NaSCN						74.3	68.9	59.8	50.9	43.7	
½Na <sub>2</sub> SiO <sub>3</sub>	144	139	136	124	116	88	72	51	38	27	19
½Na <sub>2</sub> SO <sub>4</sub>	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 <sub>2</sub> WO <sub>4</sub> (25°)	116.1	109.2	104.8	92.2	85.8						
½NiSO <sub>4</sub>	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 <sub>3</sub> ) <sub>2</sub>	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 <sub>4</sub>						216.8	121.7	66.9	47.9	32.7	
½SrCl <sub>2</sub>	114.5	108.9	105.4	94.4	90.2	75.7	68.5	58.7	49.9	42.2	
½Sr(NO <sub>3</sub> ) <sub>2</sub>	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 <sub>4</sub>						61.0	54.0	44.3	36.3	29.8	
TiCl	128.2	123.7	120.2								
TiF	113.3	108.2	105.4	97.4	92.6	78.8	71.5	62.7			
TiNO <sub>3</sub>	124.7	121.1	118.4	107.9	101.2						
½Ti <sub>2</sub> SO <sub>4</sub>	127.4	118.4	112.3	92.7	83.1						
Trichloroacetic acid (25°)						273	207	127	79	44	19
½UO <sub>2</sub> F <sub>2</sub> (25°)	26.10	12.31	9.17	5.43	4.74	3.75	3.22				
½UO <sub>2</sub> SO <sub>4</sub> (25°)	106.5	63.2	49.2	27.6	22.2	14.4	11.6				2.7
⅓YCl <sub>3</sub> (25°)	129	122	118	109							
½Zn(OAc) <sub>2</sub> (25°)	83	77	73	58	49						
½ZnCl <sub>2</sub>	107	101	98	87	82	65	55	39.6	29.6	23.2	18.5
½Zn(NO <sub>3</sub> ) <sub>2</sub>	120	114	111	100							
½ZnSO <sub>4</sub>	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

Temp., °C	Conductivity, $\mu\text{S} \cdot \text{cm}^{-1}$	Resistivity, $\text{M}\Omega \cdot \text{cm}$	Equivalent conductance, $\text{cm}^2 \cdot \text{ohm}^{-1} \cdot \text{equivalent}^{-1}$	
			$\lambda^0, \text{H}^+$	$\lambda^0, \text{OH}^-$
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)  $\kappa$ , which is defined as the reciprocal of the resistance [ $\Omega^{-1}$ ] of a 1-m cube of liquid at a specified temperature [ $\Omega^{-1} \cdot \text{m}^{-1}$ ]. 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)*

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

\* SI units are in brackets.



*Conductance of an Electrolyte Solution*

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

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

*Equivalent Conductivity*

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

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 [ $\Omega^{-1} \cdot \text{cm}^2 \cdot \text{equiv}^{-1}$ ]. The formula unit used in expressing the concentration must be specified; for example,  $\text{NaCl}$ ,  $\frac{1}{2}\text{K}_2\text{SO}_4$ ,  $\frac{1}{3}\text{LaCl}_3$ .

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  $\lambda_c^\circ$  and  $\lambda_a^\circ$  are the ionic conductances of cations and anions, respectively, at infinite dilution (Table 8.35).

*Ionic Mobility and Ionic Equivalent Conductivity*

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

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

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

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

*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*

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

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

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