APPENDIX F

Solubility Products*

Formula	pK_{sp}	K_{sp}
Azides: $L = N_3^-$		
CuL	8.31	4.9×10^{-9}
AgL	8.56	2.8×10^{-9}
Hg_2L_2	9.15	7.1×10^{-10}
TlL	3.66	2.2×10^{-4}
$PdL_2(\alpha)$	8.57	2.7×10^{-9}
Bromates: $L = BrO_3^-$		
$BaL \cdot H_2O$ (f)	5.11	7.8×10^{-6}
AgL	4.26	5.5×10^{-5}
TlL	3.78	1.7×10^{-4}
PbL_2	5.10	7.9×10^{-6}
Bromides: $L = Br^-$		
CuL	8.3	5×10^{-9}
AgL	12.30	5.0×10^{-13}
Hg_2L_2	22.25	5.6×10^{-23}
TlL	5.44	3.6×10^{-6}
HgL_2 (f)	18.9	1.3×10^{-19}
PbL_2	5.68	2.1×10^{-6}
Carbonates: $L = CO_3^{2-}$		
MgL	7.46	3.5×10^{-8}
CaL (calcite)	8.35	4.5×10^{-9}
CaL (aragonite)	8.22	6.0×10^{-9}
SrL	9.03	9.3×10^{-10}
BaL	8.30	5.0×10^{-9}
Y_2L_3	30.6	2.5×10^{-31}
La_2L_3	33.4	4.0×10^{-34}
MnL	9.30	5.0×10^{-10}
FeL	10.68	2.1×10^{-11}
CoL	9.98	1.0×10^{-10}
NiL	6.87	1.3×10^{-7}
CuL	9.63	2.3×10^{-10}
Ag_2L	11.09	8.1×10^{-12}
Hg_2L	16.05	8.9×10^{-17}
ZnL	10.00	1.0×10^{-10}
CdL	13.74	1.8×10^{-14}
PbL	13.13	7.4×10^{-14}
Chlorides: $L = Cl^-$		
CuL	6.73	1.9×10^{-7}
AgL	9.74	1.8×10^{-10}
Hg_2L_2	17.91	1.2×10^{-18}
TlL	3.74	1.8×10^{-4}
PbL_2	4.78	1.7×10^{-5}
Chromates: $L = CrO_4^{2-}$		
BaL	9.67	2.1×10^{-10}
CuL	5.44	3.6×10^{-6}
Ag_2L	11.92	1.2×10^{-12}
Hg_2L	8.70	2.0×10^{-9}
Tl_2L	12.01	9.8×10^{-13}
Cobalticyanides: $L = Co(CN)_6^{3-}$		
Ag_3L	25.41	3.9×10^{-26}
$(Hg_2)_3L_2$	36.72	1.9×10^{-37}
Cyanides: $L = CN^-$		
AgL	15.66	2.2×10^{-16}
Hg_2L_2	39.3	5×10^{-40}
ZnL_2 (h)	15.5	3×10^{-16}
Ferrocyanides: $L = Fe(CN)_6^{4-}$		
Ag_4L	44.07	8.5×10^{-45}
Zn_2L	15.68	2.1×10^{-16}
Cd_2L	17.38	4.2×10^{-18}
Pb_2L	18.02	9.5×10^{-19}
Fluorides: $L = F^-$		
LiL	2.77	1.7×10^{-3}
MgL_2	8.13	7.4×10^{-9}
CaL_2	10.50	3.2×10^{-11}
SrL_2	8.58	2.6×10^{-9}
BaL_2	5.82	1.5×10^{-6}
LaL_3	18.7	2×10^{-19}
ThL_4	28.3	5×10^{-29}
PbL_2	7.44	3.6×10^{-8}
Hydroxides: $L = OH^-$		
MgL_2 (amorphous)	9.2	6×10^{-10}
MgL_2 (brucite crystal)	11.15	7.1×10^{-12}
CaL_2	5.19	6.5×10^{-6}
$BaL_2 \cdot 8H_2O$	3.6	3×10^{-4}
YL_3	23.2	6×10^{-24}
LaL_3	20.7	2×10^{-21}
CeL_3	21.2	6×10^{-22}
UO_2 ($\rightleftharpoons U^{4+} + 4OH^-$)	56.2	6×10^{-57}
UO_2L_2 ($\rightleftharpoons UO_2^{2+} + 2OH^-$)	22.4	4×10^{-23}
MnL_2	12.8	1.6×10^{-13}
FeL_2	15.1	7.9×10^{-16}
CoL_2	14.9	1.3×10^{-15}
NiL_2	15.2	6×10^{-16}

The designations α, β, or γ after some formulas refer to particular crystalline forms (which are customarily identified by Greek letters). Data for salts except oxalates are taken mainly from A. E. Martell and R. M. Smith, Critical Stability Constants. Vol. 4 (New York: Plenum Press, 1976). Data for oxalates are from L. G. Sillén and A. E. Martell, Stability Constants of Metal-Ion Complexes, Supplement No. 1 (London: The Chemical Society, Special Publication No. 25, 1971). Another source: R. M. H. Verbeeck et al., Inorg. Chem. **1984, 23, 1922.*

Conditions are 25°C and zero ionic strength unless otherwise indicated: (a) 19°C; (b) 20°C; (c) 38°C; (d) 0.1 M; (e) 0.2 M; (f) 0.5 M; (g) 1 M; (h) 3 M; (i) 4 M; (j) 5 M.

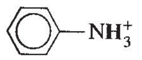
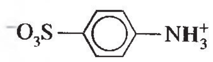
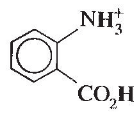
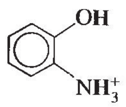
(Continued)

Formula	pK_{sp}	K_{sp}
CuL_2	19.32	4.8×10^{-20}
VL_3	34.4	4.0×10^{-35}
CrL_3 (d)	29.8	1.6×10^{-30}
FeL_3	38.8	1.6×10^{-39}
CoL_3 (a)	44.5	3×10^{-45}
VOL_2 ($\rightleftharpoons VO^{2+} + 2OH^-$)	23.5	3×10^{-24}
PdL_2	28.5	3×10^{-29}
ZnL_2 (amorphous)	15.52	3.0×10^{-16}
CdL_2 (β)	14.35	4.5×10^{-15}
HgO (red) ($\rightleftharpoons Hg^{2+} + 2OH^-$)	25.44	3.6×10^{-26}
Cu_2O ($\rightleftharpoons 2Cu^+ + 2OH^-$)	29.4	4×10^{-30}
Ag_2O ($\rightleftharpoons 2Ag^+ + 2OH^-$)	15.42	3.8×10^{-16}
AuL_3	5.5	3×10^{-6}
AlL_3 (α)	33.5	3×10^{-34}
GaL_3 (amorphous)	37	10^{-37}
InL_3	36.9	1.3×10^{-37}
SnO ($\rightleftharpoons Sn^{2+} + 2OH^-$)	26.2	6×10^{-27}
PbO (yellow) ($\rightleftharpoons Pb^{2+} + 2OH^-$)	15.1	8×10^{-16}
PbO (red) ($\rightleftharpoons Pb^{2+} + 2OH^-$)	15.3	5×10^{-16}
Iodates: L = IO_3^-		
CaL_2	6.15	7.1×10^{-7}
SrL_2	6.48	3.3×10^{-7}
BaL_2	8.81	1.5×10^{-9}
YL_3	10.15	7.1×10^{-11}
LaL_3	10.99	1.0×10^{-11}
CeL_3	10.86	1.4×10^{-11}
ThL_4 (f)	14.62	2.4×10^{-15}
UO_2L_2 ($\rightleftharpoons UO_2^{2+} + 2IO_3^-$)(e)	7.01	9.8×10^{-8}
CrL_3 (f)	5.3	5×10^{-6}
AgL	7.51	3.1×10^{-8}
Hg_2L_2	17.89	1.3×10^{-18}
TlL	5.51	3.1×10^{-6}
ZnL_2	5.41	3.9×10^{-6}
CdL_2	7.64	2.3×10^{-8}
PbL_2	12.61	2.5×10^{-13}
Iodides: L = I^-		
CuL	12.0	1×10^{-12}
AgL	16.08	8.3×10^{-17}
CH_3HgL ($\rightleftharpoons CH_3Hg^+ + I^-$) (b, g)	11.46	3.5×10^{-12}
CH_3CH_2HgL ($\rightleftharpoons CH_3CH_2Hg^+ + I^-$)	4.11	7.8×10^{-5}
TlL	7.23	5.9×10^{-8}
Hg_2L_2	28.34	4.6×10^{-29}
SnL_2 (i)	5.08	8.3×10^{-6}
PbL_2	8.10	7.9×10^{-9}
Oxalates: L = $C_2O_4^{2-}$		
CaL (b, d)	7.9	1.3×10^{-8}
SrL (b, d)	6.4	4×10^{-7}
BaL (b, d)	6.0	1×10^{-6}
La_2L_3 (b, d)	25.0	1×10^{-25}
ThL_2 (g)	21.38	4.2×10^{-22}
UO_2L ($\rightleftharpoons UO_2^{2+} + C_2O_4^{2-}$) (b, d)	8.66	2.2×10^{-9}

Formula	pK_{sp}	K_{sp}
Phosphates: L = PO_4^{3-}		
$MgHL \cdot 3H_2O$ ($\rightleftharpoons Mg^{2+} + HL^{2-}$)	5.78	1.7×10^{-6}
$CaHL \cdot 2H_2O$ ($\rightleftharpoons Ca^{2+} + HL^{2-}$)	6.58	2.6×10^{-7}
SrHL ($\rightleftharpoons Sr^{2+} + HL^{2-}$) (b)	6.92	1.2×10^{-7}
BaHL ($\rightleftharpoons Ba^{2+} + HL^{2-}$) (b)	7.40	4.0×10^{-8}
LaL (f)	22.43	3.7×10^{-23}
$Fe_3L_2 \cdot 8H_2O$	36.0	1×10^{-36}
$FeL \cdot 2H_2O$	26.4	4×10^{-27}
$(VO)_3L_2$ ($\rightleftharpoons 3VO^{2+} + 2L^{3-}$)	25.1	8×10^{-26}
Ag_3L	17.55	2.8×10^{-18}
Hg_2HL ($\rightleftharpoons Hg_2^{2+} + HL^{2-}$)	12.40	4.0×10^{-13}
$Zn_3L_2 \cdot 4H_2O$	35.3	5×10^{-36}
Pb_3L_2 (c)	43.53	3.0×10^{-44}
GaL (g)	21.0	1×10^{-21}
InL (g)	21.63	2.3×10^{-22}
Sulfates: L = SO_4^{2-}		
CaL	4.62	2.4×10^{-5}
SrL	6.50	3.2×10^{-7}
BaL	9.96	1.1×10^{-10}
RaL (b)	10.37	4.3×10^{-11}
Ag_2L	4.83	1.5×10^{-5}
Hg_2L	6.13	7.4×10^{-7}
PbL	6.20	6.3×10^{-7}
Sulfides: L = S^{2-}		
MnL (pink)	10.5	3×10^{-11}
MnL (green)	13.5	3×10^{-14}
FeL	18.1	8×10^{-19}
CoL (α)	21.3	5×10^{-22}
CoL (β)	25.6	3×10^{-26}
NiL (α)	19.4	4×10^{-20}
NiL (β)	24.9	1.3×10^{-25}
NiL (γ)	26.6	3×10^{-27}
CuL	36.1	8×10^{-37}
Cu_2L	48.5	3×10^{-49}
Ag_2L	50.1	8×10^{-51}
Tl_2L	21.2	6×10^{-22}
ZnL (α)	24.7	2×10^{-25}
ZnL (β)	22.5	3×10^{-23}
CdL	27.0	1×10^{-27}
HgL (black)	52.7	2×10^{-53}
HgL (red)	53.3	5×10^{-54}
SnL	25.9	1.3×10^{-26}
PbL	27.5	3×10^{-28}
In_2L_3	69.4	4×10^{-70}
Thiocyanates: L = SCN^-		
CuL (j)	13.40	4.0×10^{-14}
AgL	11.97	1.1×10^{-12}
Hg_2L_2	19.52	3.0×10^{-20}
TlL	3.79	1.6×10^{-4}
HgL_2	19.56	2.8×10^{-20}

APPENDIX G

Acid Dissociation Constants

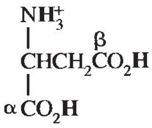
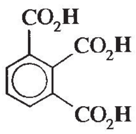
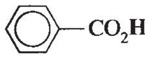
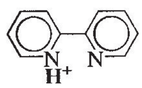
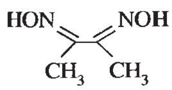
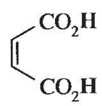
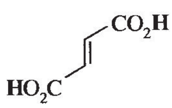
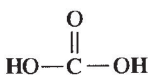
Name	Structure*	pK_a[†]	K_a[‡]
Acetic acid (ethanoic acid)	CH_3CO_2H	4.756	1.75×10^{-5}
Alanine	$\overset{NH_3^+}{\mid}$ $CHCH_3$ $\underset{CO_2H}{\mid}$	2.344 (CO_2H) 9.868 (NH_3)	4.53×10^{-3} 1.36×10^{-10}
Aminobenzene (aniline)		4.601	2.51×10^{-5}
4-Aminobenzenesulfonic acid (sulfanilic acid)		3.232	5.86×10^{-4}
2-Aminobenzoic acid (anthranilic acid)		2.08 (CO_2H) 4.96 (NH_3)	8.3×10^{-3} 1.10×10^{-5}
2-Aminoethanethiol (2-mercaptoethylamine)	$HSCH_2CH_2NH_3^+$	8.21 (SH) ($\mu = 0.1$) 10.73 (NH_3) ($\mu = 0.1$)	6.2×10^{-9} 1.86×10^{-11}
2-Aminoethanol (ethanolamine)	$HOCH_2CH_2NH_3^+$	9.498	3.18×10^{-10}
2-Aminophenol		4.70 (NH_3) (20°) 9.97 (OH) (20°)	2.0×10^{-5} 1.05×10^{-10}
Ammonia	NH_4^+	9.245	5.69×10^{-10}
Arginine	$\overset{NH_3^+}{\mid}$ $CHCH_2CH_2CH_2NHC(=NH_2^+)NH_2$ $\underset{CO_2H}{\mid}$	1.823 (CO_2H) 8.991 (NH_3) (12.1) (NH_2) ($\mu = 0.1$)	1.50×10^{-2} 1.02×10^{-9} 8×10^{-13}
Arsenic acid (hydrogen arsenate)	$HO{-}As(=O)(OH){-}OH$	2.31 7.05 11.9	4.9×10^{-3} 8.9×10^{-8} 1.3×10^{-12}
Arsenious acid (hydrogen arsenite)	$As(OH)_3$	9.29	5.1×10^{-10}
Asparagine	$\overset{NH_3^+}{\mid}$ $CHCH_2CNH_2$ (C=O) $\underset{CO_2H}{\mid}$	2.16 (CO_2H) ($\mu = 0.1$) 8.73 (NH_3) ($\mu = 0.1$)	6.9×10^{-3} 1.86×10^{-9}

Each acid is written in its protonated form. The acidic protons are indicated in bold type.

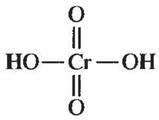
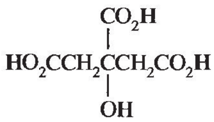
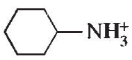
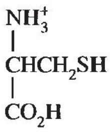
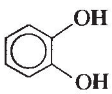
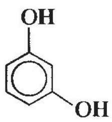
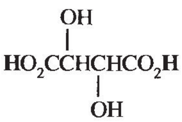
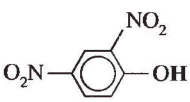
[†] *pK_a values refer to 25°C and zero ionic strength unless otherwise indicated. Values in parentheses are considered to be less reliable. Data are from A. E. Martell, R. M. Smith, and R. J. Motekaitis, NIST Database 46 (Gaithersburg, MD: National Institute of Standards and Technology, 2001).*

[‡] *The accurate way to calculate K_b for the conjugate base is $pK_b = 13.995 - pK_a$ and $K_b = 10^{-pK_b}$.*

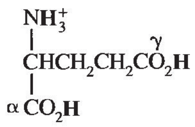
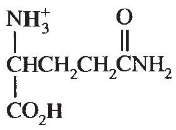
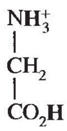
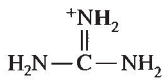
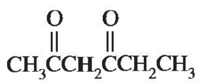
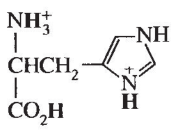
(Continued)

Name	Structure	pK_a	K_a
Aspartic acid		1.990 (α-CO_2H) 3.900 (β-CO_2H) 10.002 (NH_3)	1.02×10^{-2} 1.26×10^{-4} 9.95×10^{-11}
Aziridine (dimethyleneimine)		8.04	9.1×10^{-9}
Benzene-1,2,3-tricarboxylic acid (hemimellitic acid)		2.86 4.30 6.28	1.38×10^{-3} 5.0×10^{-5} 5.2×10^{-7}
Benzoic acid		4.202	6.28×10^{-5}
Benzylamine		9.35	4.5×10^{-10}
2,2′-Bipyridine		4.34	4.6×10^{-5}
Boric acid (hydrogen borate)	$B(OH)_3$	9.237 (12.74) (20°) (13.80) (20°)	5.79×10^{-10} 1.82×10^{-13} 1.58×10^{-14}
Bromoacetic acid	$BrCH_2CO_2H$	2.902	1.25×10^{-3}
Butane-2,3-dione dioxime (dimethylglyoxime)		10.66 12.0	2.2×10^{-11} 1×10^{-12}
Butanoic acid	$CH_3CH_2CH_2CO_2H$	4.818	1.52×10^{-5}
cis-Butenedioic acid (maleic acid)		1.92 6.27	1.20×10^{-2} 5.37×10^{-7}
trans-Butenedioic acid (fumaric acid)		3.02 4.48	9.5×10^{-4} 3.3×10^{-5}
Butylamine	$CH_3CH_2CH_2CH_2NH_3^+$	10.640	2.29×10^{-11}
Carbonic acid* (hydrogen carbonate)		6.351 10.329	4.46×10^{-7} 4.69×10^{-11}
Chloroacetic acid	$ClCH_2CO_2H$	2.865	1.36×10^{-3}
3-Chloropropanoic acid	$ClCH_2CH_2CO_2H$	4.11	7.8×10^{-5}
Chlorous acid (hydrogen chlorite)	HOCl=O	1.96	1.10×10^{-2}

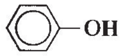
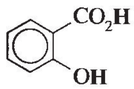
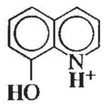
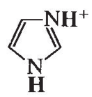
The concentration of "carbonic acid" is considered to be the sum $[H_2CO_3] + [CO_2(aq)]$. See Box 6-4.

Name	Structure	pK_a	K_a
Chromic acid (hydrogen chromate)		−0.2 (20°) 6.51	1.6 3.1×10^{-7}
Citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid)		3.128 4.761 6.396	7.44×10^{-4} 1.73×10^{-5} 4.02×10^{-7}
Cyanoacetic acid	$NCCH_2CO_2H$	2.472	3.37×10^{-3}
Cyclohexylamine		10.567	2.71×10^{-11}
Cysteine		(1.7) (CO_2H) 8.36 (SH) 10.74 (NH_3)	2×10^{-2} 4.4×10^{-9} 1.82×10^{-11}
Dichloroacetic acid	Cl_2CHCO_2H	(1.1)	8×10^{-2}
Diethylamine	$(CH_3CH_2)_2NH_2^+$	11.00	1.0×10^{-11}
1,2-Dihydroxybenzene (catechol)		9.41 (13.3) ($\mu = 0.1$)	3.9×10^{-10} 5.0×10^{-14}
1,3-Dihydroxybenzene (resorcinol)		9.30 ($\mu = 0.1$) 11.06 ($\mu = 0.1$)	5.0×10^{-10} 8.7×10^{-12}
D-2,3-Dihydroxybutanedioic acid (D-tartaric acid)		3.036 4.366	9.20×10^{-4} 4.31×10^{-5}
2,3-Dimercaptopropanol		8.63 ($\mu = 0.1$) 10.65 ($\mu = 0.1$)	2.3×10^{-9} 2.2×10^{-11}
Dimethylamine	$(CH_3)_2NH_2^+$	10.774	1.68×10^{-11}
2,4-Dinitrophenol		4.114	7.69×10^{-5}
Ethane-1,2-dithiol	$HSCH_2CH_2SH$	8.85 (30°, $\mu = 0.1$) 10.43 (30°, $\mu = 0.1$)	1.4×10^{-9} 3.7×10^{-11}
Ethylamine	$CH_3CH_2NH_3^+$	10.673	2.12×10^{-11}
Ethylenediamine (1,2-diaminoethane)	$H_3\overset{+}{N}CH_2CH_2\overset{+}{N}H_3$	6.848 9.928	1.42×10^{-7} 1.18×10^{-10}

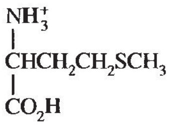
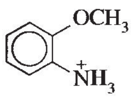
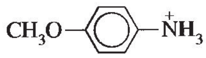
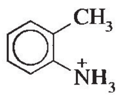
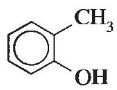
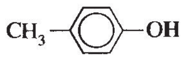
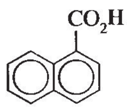
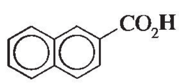
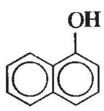
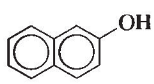
(Continued)

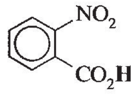
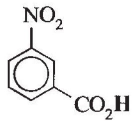
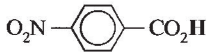
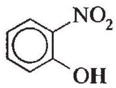
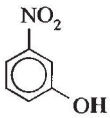
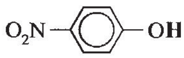
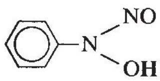
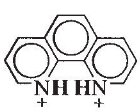
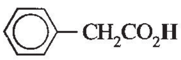
Name	Structure	pK_a	K_a
Ethylenedinitrilotetraacetic acid (EDTA)	$(HO_2CCH_2)_2\overset{+}{N}HCH_2CH_2\overset{+}{N}H(CH_2CO_2H)_2$	(0.0) (CO_2H) (μ = 1.0) (1.5) (CO_2H) (μ = 0.1) 2.00 (CO_2H) (μ = 0.1) 2.69 (CO_2H) (μ = 0.1) 6.13 (NH) (μ = 0.1) 10.37 (NH) (μ = 0.1)	1.0 0.032 0.010 0.002 0 7.4×10^{-7} 4.3×10^{-11}
Formic acid (methanoic acid)	HCO_2H	3.744	1.80×10^{-4}
Glutamic acid		2.160 (α-CO_2H) 4.30 (γ-CO_2H) 9.96 (NH_3)	6.92×10^{-3} 5.0×10^{-5} 1.10×10^{-10}
Glutamine		2.19 (CO_2H) (μ = 0.1) 9.00 (NH_3) (μ = 0.1)	6.5×10^{-3} 1.00×10^{-9}
Glycine (aminoacetic acid)		2.350 (CO_2H) 9.778 (NH_3)	4.47×10^{-3} 1.67×10^{-10}
Guanidine		(13.5) (μ = 1.0)	3×10^{-14}
1,6-Hexanedioic acid (adipic acid)	$HO_2CCH_2CH_2CH_2CH_2CO_2H$	4.424 5.420	3.77×10^{-5} 3.80×10^{-6}
Hexane-2,4-dione		9.38	4.2×10^{-10}
Histidine		1.6 (CO_2H) 5.97 (NH) 9.28 (NH_3)	3×10^{-2} 1.07×10^{-6} 5.2×10^{-10}
Hydrazine	$H_3\overset{+}{N}-\overset{+}{N}H_3$	−0.99 8.02	9.8 9.5×10^{-9}
Hydrazoic acid (hydrogen azide)	$HN{=}\overset{+}{N}{=}\overset{-}{N}$	4.65	2.2×10^{-5}
Hydrogen cyanate	$HOC{\equiv}N$	3.48	3.3×10^{-4}
Hydrogen cyanide	$HC{\equiv}N$	9.21	6.2×10^{-10}
Hydrogen fluoride	HF	3.17	6.8×10^{-4}
Hydrogen peroxide	HOOH	11.65	2.2×10^{-12}
Hydrogen sulfide	H_2S	7.02 14.0*	9.5×10^{-8} $1.0 \times 10^{-14*}$
Hydrogen thiocyanate	$HSC{\equiv}N$	(1.1) (20°C)	0.08
Hydroxyacetic acid (glycolic acid)	$HOCH_2CO_2H$	3.832	1.48×10^{-4}

*D. J. Phillips and S. L. Phillips. "High Temperature Dissociation Constants of HS^- and the Standard Thermodynamic Values for S^{2-}," *J. Chem. Eng. Data* **2000**, *45*, 981.*

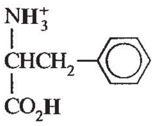
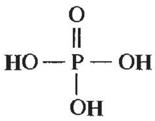
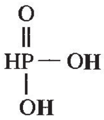
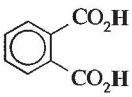
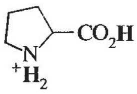
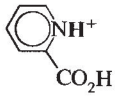
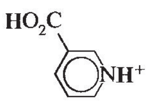
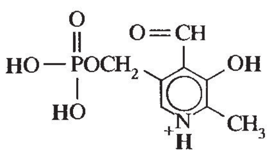
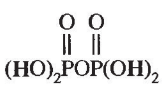
Name	Structure	pK_a	K_a
Hydroxybenzene (phenol)		9.997	1.01×10^{-10}
2-Hydroxybenzoic acid (salicylic acid)		2.972 (CO_2H) (13.7) (OH)	1.07×10^{-3} 2×10^{-14}
L-Hydroxybutanedioic acid (malic acid)	$HO_2CCH_2CH(OH)CO_2H$	3.459 5.097	3.48×10^{-4} 8.00×10^{-6}
Hydroxylamine	$HO\overset{+}{N}H_3$	5.96 (NH) (13.74) (OH)	1.10×10^{-6} 1.8×10^{-14}
8-Hydroxyquinoline (oxine)		4.94 (NH) 9.82 (OH)	1.15×10^{-5} 1.51×10^{-10}
Hypobromous acid (hydrogen hypobromite)	HOBr	8.63	2.3×10^{-9}
Hypochlorous acid (hydrogen hypochlorite)	HOCl	7.53	3.0×10^{-8}
Hypoiodous acid (hydrogen hypoiodite)	HOI	10.64	2.3×10^{-11}
Hypophosphorous acid (hydrogen hypophosphite)	$H_2P(=O)OH$	(1.3)	5×10^{-2}
Imidazole (1,3-diazole)		6.993 (14.5)	1.02×10^{-7} 3×10^{-15}
Iminodiacetic acid	$H_2\overset{+}{N}(CH_2CO_2H)_2$	1.85 (CO_2H) 2.84 (CO_2H) 9.79 (NH_2)	1.41×10^{-2} 1.45×10^{-3} 1.62×10^{-10}
Iodic acid (hydrogen iodate)	$HOI(=O)=O$	0.77	0.17
Iodoacetic acid	ICH_2CO_2H	3.175	6.68×10^{-4}
Isoleucine	NH_3^+–$CHCH(CH_3)CH_2CH_3$–CO_2H	2.318 (CO_2H) 9.758 (NH_3)	4.81×10^{-3} 1.75×10^{-10}
Leucine	NH_3^+–$CHCH_2CH(CH_3)_2$–CO_2H	2.328 (CO_2H) 9.744 (NH_3)	4.70×10^{-3} 1.80×10^{-10}
Lysine	$\alpha\ NH_3^+$–$CHCH_2CH_2CH_2CH_2\overset{\epsilon}{N}H_3^+$–$CO_2H$	(1.77) (CO_2H) 9.07 (α-NH_3) 10.82 (ϵ-NH_3)	1.7×10^{-2} 8.5×10^{-10} 1.51×10^{-11}

(Continued)

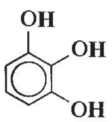
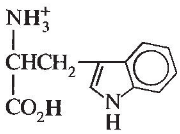
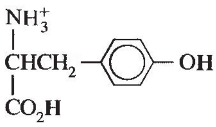
Name	Structure	pK_a	K_a
Malonic acid (propanedioic acid)	$HO_2CCH_2CO_2H$	2.847 5.696	1.42×10^{-3} 2.01×10^{-6}
Mercaptoacetic acid (thioglycolic acid)	$HSCH_2CO_2H$	3.64 (CO_2H) 10.61 (SH)	2.3×10^{-4} 2.5×10^{-11}
2-Mercaptoethanol	$HSCH_2CH_2OH$	9.7_5	1.8×10^{-10}
Methionine		2.18 (CO_2H) ($\mu = 0.1$) 9.08 (NH_3) ($\mu = 0.1$)	6.6×10^{-3} 8.3×10^{-10}
2-Methoxyaniline (*o*-anisidine)		4.526	2.98×10^{-5}
4-Methoxyaniline (*p*-anisidine)		5.357	4.40×10^{-6}
Methylamine	$CH_3\overset{+}{N}H_3$	10.645	2.26×10^{-11}
2-Methylaniline (*o*-toluidine)		4.447	3.57×10^{-5}
4-Methylaniline (*p*-toluidine)		5.080	8.32×10^{-6}
2-Methylphenol (*o*-cresol)		10.31	4.9×10^{-11}
4-Methylphenol (*p*-cresol)		10.269	5.5×10^{-11}
Morpholine (perhydro-1,4-oxazine)		8.492	3.22×10^{-9}
1-Naphthoic acid		3.67	2.1×10^{-4}
2-Naphthoic acid		4.16	6.9×10^{-5}
1-Naphthol		9.416	3.84×10^{-10}
2-Naphthol		9.573	2.67×10^{-10}
Nitrilotriacetic acid	$H\overset{+}{N}(CH_2CO_2H)_3$	(1.0) (CO_2H) (25°, $\mu = 0.1$) 2.0 (CO_2H) (25°) 2.940 (CO_2H) (20°) 10.334 (NH) (20°)	0.10 0.010 1.15×10^{-3} 4.63×10^{-11}

Name	Structure	pK_a	K_a
2-Nitrobenzoic acid		2.185	6.53×10^{-3}
3-Nitrobenzoic acid		3.449	3.56×10^{-4}
4-Nitrobenzoic acid		3.442	3.61×10^{-4}
Nitroethane	$CH_3CH_2NO_2$	8.57	2.7×10^{-9}
2-Nitrophenol		7.230	5.89×10^{-8}
3-Nitrophenol		8.37	4.3×10^{-9}
4-Nitrophenol		7.149	7.10×10^{-8}
N-Nitrosophenylhydroxylamine (cupferron)		4.16 ($\mu = 0.1$)	6.9×10^{-5}
Nitrous acid	HON=O	3.15	7.1×10^{-4}
Oxalic acid (ethanedioic acid)	HO_2CCO_2H	1.27 4.266	5.4×10^{-2} 5.42×10^{-5}
Oxoacetic acid (glyoxylic acid)	$H\overset{O}{\overset{\|}{C}}CO_2H$	3.46	3.5×10^{-4}
Oxobutanedioic acid (oxaloacetic acid)	$HO_2CCH_2\overset{O}{\overset{\|}{C}}CO_2H$	2.56 4.37	2.8×10^{-3} 4.3×10^{-5}
2-Oxopentanedioic (α-ketoglutaric acid)	$HO_2CCH_2CH_2\overset{O}{\overset{\|}{C}}CO_2H$	(1.90) ($\mu = 0.5$) 4.44 ($\mu = 0.5$)	1.26×10^{-2} 3.6×10^{-5}
2-Oxopropanoic acid (pyruvic acid)	$CH_3\overset{O}{\overset{\|}{C}}CO_2H$	2.48	3.3×10^{-3}
1,5-Pentanedioic acid (glutaric acid)	$HO_2CCH_2CH_2CH_2CO_2H$	4.345 5.422	4.52×10^{-5} 3.78×10^{-6}
Pentanoic acid (valeric acid)	$CH_3CH_2CH_2CH_2CO_2H$	4.843	1.44×10^{-5}
1,10-Phenanthroline		(1.8) ($\mu = 0.1$) 4.91	1.6×10^{-2} 1.23×10^{-5}
Phenylacetic acid		4.310	4.90×10^{-5}

(Continued)

Name	Structure	pK_a	K_a
Phenylalanine		2.20 (CO_2H) 9.31 (NH_3)	6.3×10^{-3} 4.9×10^{-10}
Phosphoric acid* (hydrogen phosphate)		2.148 7.198 12.375	7.11×10^{-3} 6.34×10^{-8} 4.22×10^{-13}
Phosphorous acid (hydrogen phosphite)		(1.5) 6.78	3×10^{-2} 1.66×10^{-7}
Phthalic acid (benzene-1,2-dicarboxylic acid)		2.950 5.408	1.12×10^{-3} 3.90×10^{-6}
Piperazine (perhydro-1,4-diazine)		5.333 9.731	4.65×10^{-6} 1.86×10^{-10}
Piperidine		11.125	7.50×10^{-12}
Proline		1.952 (CO_2H) 10.640 (NH_2)	1.12×10^{-2} 2.29×10^{-11}
Propanoic acid	$CH_3CH_2CO_2H$	4.874	1.34×10^{-5}
Propenoic acid (acrylic acid)	$H_2C{=}CHCO_2H$	4.258	5.52×10^{-5}
Propylamine	$CH_3CH_2CH_2NH_3^+$	10.566	2.72×10^{-11}
Pyridine (azine)		5.20	6.3×10^{-6}
Pyridine-2-carboxylic acid (picolinic acid)		(1.01) (CO_2H) 5.39 (NH)	9.8×10^{-2} 4.1×10^{-6}
Pyridine-3-carboxylic acid (nicotinic acid)		2.03 (CO_2H) 4.82 (NH)	9.3×10^{-3} 1.51×10^{-5}
Pyridoxal-5-phosphate		1.4 (POH) ($\mu = 0.1$) 3.44 (OH) ($\mu = 0.1$) 6.01 (POH) ($\mu = 0.1$) 8.45 (NH) ($\mu = 0.1$)	0.04 3.6×10^{-4} 9.8×10^{-7} 3.5×10^{-9}
Pyrophosphoric acid (hydrogen diphosphate)		0.83 2.26 6.72 9.46	0.15 5.5×10^{-3} 1.9×10^{-7} 3.5×10^{-10}

*pK_3 *from A. G. Miller and J. W. Macklin, Anal. Chem.* **1983**, *55, 684.*

Name	Structure	pK_a	K_a
Pyrrolidine		11.305	4.95×10^{-12}
Serine	NH_3^+ — $CHCH_2OH$ — CO_2H	2.187 (CO_2H) 9.209 (NH_3)	6.50×10^{-3} 6.18×10^{-10}
Succinic acid (butanedioic acid)	$HO_2CCH_2CH_2CO_2H$	4.207 5.636	6.21×10^{-5} 2.31×10^{-6}
Sulfuric acid (hydrogen sulfate)	HO—S(=O)(=O)—OH	1.987 (pK_2)	1.03×10^{-2}
Sulfurous acid (hydrogen sulfite)	HOS(=O)OH	1.857 7.172	1.39×10^{-2} 6.73×10^{-8}
Thiosulfuric acid (hydrogen thiosulfate)	HOS(=O)(=O)SH	(0.6) (1.6)	0.3 0.03
Threonine	NH_3^+ — $CHCHOHCH_3$ — CO_2H	2.088 (CO_2H) 9.100 (NH_3)	8.17×10^{-3} 7.94×10^{-10}
Trichloroacetic acid	Cl_3CCO_2H	(0.5)	0.3
Triethanolamine	$(HOCH_2CH_2)_3NH^+$	7.762	1.73×10^{-8}
Triethylamine	$(CH_3CH_2)_3NH^+$	10.72	1.9×10^{-11}
1,2,3-Trihydroxybenzene (pyrogallol)		8.96 (25°, $\mu = 0.1$) 11.00 (25°, $\mu = 0.1$) (14.0) (20°, $\mu = 0.1$)	1.10×10^{-9} 1.00×10^{-11} 10^{-14}
Trimethylamine	$(CH_3)_3NH^+$	9.799	1.59×10^{-10}
Tris(hydroxymethyl)amino- methane (tris or tham)	$(HOCH_2)_3CNH_3^+$	8.072	8.47×10^{-9}
Tryptophan		2.37 (CO_2H) ($\mu = 0.1$) 9.33 (NH_3) ($\mu = 0.1$)	4.3×10^{-3} 4.7×10^{-10}
Tyrosine		2.41 (CO_2H) ($\mu = 0.1$) 8.67 (NH_3) ($\mu = 0.1$) 11.01 (OH) ($\mu = 0.1$)	3.9×10^{-3} 2.1×10^{-9} 9.8×10^{-12}
Valine	NH_3^+ — $CHCH(CH_3)_2$ — CO_2H	2.286 (CO_2H) 9.719 (NH_3)	5.18×10^{-3} 1.91×10^{-10}
Water*	H_2O	13.997	1.01×10^{-14}

**The constant given for water is K_w.*

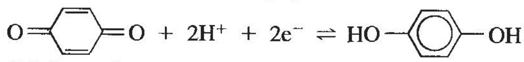
APPENDIX H

Standard Reduction Potentials*

Reaction	E° (volts)	dE°/dT (mV/K)
Aluminum		
$Al^{3+} + 3e^- \rightleftharpoons Al(s)$	−1.677	0.533
$AlCl^{2+} + 3e^- \rightleftharpoons Al(s) + Cl^-$	−1.802	
$AlF_6^{3-} + 3e^- \rightleftharpoons Al(s) + 6F^-$	−2.069	
$Al(OH)_4^- + 3e^- \rightleftharpoons Al(s) + 4OH^-$	−2.328	−1.13
Antimony		
$SbO^+ + 2H^+ + 3e^- \rightleftharpoons Sb(s) + H_2O$	0.208	
$Sb_2O_3(s) + 6H^+ + 6e^- \rightleftharpoons 2Sb(s) + 3H_2O$	0.147	−0.369
$Sb(s) + 3H^+ + 3e^- \rightleftharpoons SbH_3(g)$	−0.510	−0.030
Arsenic		
$H_3AsO_4 + 2H^+ + 2e^- \rightleftharpoons H_3AsO_3 + H_2O$	0.575	−0.257
$H_3AsO_3 + 3H^+ + 3e^- \rightleftharpoons As(s) + 3H_2O$	0.247 5	−0.505
$As(s) + 3H^+ + 3e^- \rightleftharpoons AsH_3(g)$	−0.238	−0.029
Barium		
$Ba^{2+} + 2e^- + Hg \rightleftharpoons Ba(in\ Hg)$	−1.717	
$Ba^{2+} + 2e^- \rightleftharpoons Ba(s)$	−2.906	−0.401
Beryllium		
$Be^{2+} + 2e^- \rightleftharpoons Be(s)$	−1.968	0.60
Bismuth		
$Bi^{3+} + 3e^- \rightleftharpoons Bi(s)$	0.308	0.18
$BiCl_4^- + 3e^- \rightleftharpoons Bi(s) + 4Cl^-$	0.16	
$BiOCl(s) + 2H^+ + 3e^- \rightleftharpoons Bi(s) + H_2O + Cl^-$	0.160	
Boron		
$2B(s) + 6H^+ + 6e^- \rightleftharpoons B_2H_6(g)$	−0.150	−0.296
$B_4O_7^{2-} + 14H^+ + 12e^- \rightleftharpoons 4B(s) + 7H_2O$	−0.792	
$B(OH)_3 + 3H^+ + 3e^- \rightleftharpoons B(s) + 3H_2O$	−0.889	−0.492
Bromine		
$BrO_4^- + 2H^+ + 2e^- \rightleftharpoons BrO_3^- + H_2O$	1.745	−0.511
$HOBr + H^+ + e^- \rightleftharpoons \frac{1}{2}Br_2(l) + H_2O$	1.584	−0.75
$BrO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}Br_2(l) + 3H_2O$	1.513	−0.419
$Br_2(aq) + 2e^- \rightleftharpoons 2Br^-$	1.098	−0.499
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-$	1.078	−0.611
$Br_3^- + 2e^- \rightleftharpoons 3Br^-$	1.062	−0.512
$BrO^- + H_2O + 2e^- \rightleftharpoons Br^- + 2OH^-$	0.766	−0.94
$BrO_3^- + 3H_2O + 6e^- \rightleftharpoons Br^- + 6OH^-$	0.613	−1.287
Cadmium		
$Cd^{2+} + 2e^- + Hg \rightleftharpoons Cd(in\ Hg)$	−0.380	
$Cd^{2+} + 2e^- \rightleftharpoons Cd(s)$	−0.402	−0.029
$Cd(C_2O_4)(s) + 2e^- \rightleftharpoons Cd(s) + C_2O_4^{2-}$	−0.522	
$Cd(C_2O_4)_2^{2-} + 2e^- \rightleftharpoons Cd(s) + 2C_2O_4^{2-}$	−0.572	
$Cd(NH_3)_4^{2+} + 2e^- \rightleftharpoons Cd(s) + 4NH_3$	−0.613	
$CdS(s) + 2e^- \rightleftharpoons Cd(s) + S^{2-}$	−1.175	
Calcium		
$Ca(s) + 2H^+ + 2e^- \rightleftharpoons CaH_2(s)$	0.776	
$Ca^{2+} + 2e^- + Hg \rightleftharpoons Ca(in\ Hg)$	−2.003	
$Ca^{2+} + 2e^- \rightleftharpoons Ca(s)$	−2.868	−0.186

**All species are aqueous unless otherwise indicated. The reference state for amalgams is an infinitely dilute solution of the element in Hg. The temperature coefficient, dE°/dT, allows us to calculate the standard potential, $E^\circ(T)$, at temperature T: $E^\circ(T) = E^\circ + (dE^\circ/dT)\Delta T$, where ΔT is $T - 298.15$ K. Note the units mV/K for dE°/dT. Once you know E° for a net cell reaction at temperature T, you can find the equilibrium constant, K, for the reaction from the formula $K = 10^{nFE^\circ/RT \ln 10}$, where n is the number of electrons in each half-reaction, F is the Faraday constant, and R is the gas constant.*

*SOURCES: The most authoritative source is S. G. Bratsch, J. Phys. Chem. Ref. Data **1989**, 18, 1. Additional data come from L. G. Sillen and A. E. Martell, Stability Constants of Metal-Ion Complexes (London: The Chemical Society, Special Publications Nos. 17 and 25. 1964 and 1971); G. Milazzo and S. Caroli, Tables of Standard Electrode Potentials (New York: Wiley, 1978); T. Mussini, P. Longhi, and S. Rondinini, Pure Appl. Chem. **1985**, 57, 169. Another good source is A. J. Bard, R. Parsons, and J. Jordan. Standard Potentials in Aqueous Solution (New York: Marcel Dekker, 1985). Reduction potentials for 1 200 free radical reactions are given by P. Wardman, J. Phys. Chem. Ref. Data **1989**, 18, 1637.*

Reaction	E° (volts)		dE°/dT (mV/K)
Ca(acetate)$^{+}$ + 2e^{-} ⇌ Ca(*s*) + acetate^{-}	−2.891		
$CaSO_4$(*s*) + 2e^{-} ⇌ Ca(*s*) + SO_4^{2-}	−2.936		
Ca(malonate)(*s*) + 2e^{-} ⇌ Ca(*s*) + malonate^{2-}	−3.608		
Carbon			
C_2H_2(*g*) + 2H^{+} + 2e^{-} ⇌ C_2H_4(*g*)	0.731		
	0.700		
CH_3OH + 2H^{+} + 2e^{-} ⇌ CH_4(*g*) + H_2O	0.583		−0.039
Dehydroascorbic acid + 2H^{+} + 2e^{-} ⇌ ascorbic acid + H_2O	0.390		
$(CN)_2$(*g*) + 2H^{+} + 2e^{-} ⇌ 2HCN(*aq*)	0.373		
H_2CO + 2H^{+} + 2e^{-} ⇌ CH_3OH	0.237		
C(*s*) + 4H^{+} + 4e^{-} ⇌ CH_4(*g*)	0.131 5		−0.51
HCO_2H + 2H^{+} + 2e^{-} ⇌ H_2CO + H_2O	−0.029		−0.209 2
CO_2(*g*) + 2H^{+} + 2e^{-} ⇌ CO(*g*) + H_2O	−0.103 8		−0.63
CO_2(*g*) + 2H^{+} + 2e^{-} ⇌ HCO_2H	−0.114		−0.397 7
2CO_2(*g*) + 2H^{+} + 2e^{-} ⇌ $H_2C_2O_4$	−0.432		−0.94
			−1.76
Cerium			
Ce^{4+} + e^{-} ⇌ Ce^{3+}	1.72		1.54
	1.70	1 F $HClO_4$	
	1.44	1 F H_2SO_4	
	1.61	1 F HNO_3	
	1.47	1 F HCl	
Ce^{3+} + 3e^{-} ⇌ Ce(*s*)	−2.336		0.280
Cesium			
Cs^{+} + e^{-} + Hg ⇌ Cs(*in Hg*)	−1.950		
Cs^{+} + e^{-} ⇌ Cs(*s*)	−3.026		−1.172
Chlorine			
$HClO_2$ + 2H^{+} + 2e^{-} ⇌ HOCl + H_2O	1.674		0.55
HClO + H^{+} + e^{-} ⇌ $\frac{1}{2}Cl_2$(*g*) + H_2O	1.630		−0.27
ClO_3^{-} + 6H^{+} + 5e^{-} ⇌ $\frac{1}{2}Cl_2$(*g*) + 3H_2O	1.458		−0.347
Cl_2(*aq*) + 2e^{-} ⇌ 2Cl^{-}	1.396		−0.72
Cl_2(*g*) + 2e^{-} ⇌ 2Cl^{-}	1.360 4		−1.248
ClO_4^{-} + 2H^{+} + 2e^{-} ⇌ ClO_3^{-} + H_2O	1.226		−0.416
ClO_3^{-} + 3H^{+} + 2e^{-} ⇌ $HClO_2$ + H_2O	1.157		−0.180
ClO_3^{-} + 2H^{+} + e^{-} ⇌ ClO_2 + H_2O	1.130		0.074
ClO_2 + e^{-} ⇌ ClO_2^{-}	1.068		−1.335
Chromium			
$Cr_2O_7^{2-}$ + 14H^{+} + 6e^{-} ⇌ 2Cr^{3+} + 7H_2O	1.36		−1.32
CrO_4^{2-} + 4H_2O + 3e^{-} ⇌ $Cr(OH)_3$ (*s*, hydrated) + 5OH^{-}	−0.12		−1.62
Cr^{3+} + e^{-} ⇌ Cr^{2+}	−0.42		1.4
Cr^{3+} + 3e^{-} ⇌ Cr(*s*)	−0.74		0.44
Cr^{2+} + 2e^{-} ⇌ Cr(*s*)	−0.89		−0.04
Cobalt			
Co^{3+} + e^{-} ⇌ Co^{2+}	1.92		1.23
	1.817	8 F H_2SO_4	
	1.850	4 F HNO_3	
$Co(NH_3)_5(H_2O)^{3+}$ + e^{-} ⇌ $Co(NH_3)_5(H_2O)^{2+}$	0.37	1 F NH_4NO_3	
$Co(NH_3)_6^{3+}$ + e^{-} ⇌ $Co(NH_3)_6^{2+}$	0.1		
$CoOH^{+}$ + H^{+} + 2e^{-} ⇌ Co(*s*) + H_2O	0.003		−0.04
Co^{2+} + 2e^{-} ⇌ Co(*s*)	−0.282		0.065
$Co(OH)_2$(*s*) + 2e^{-} ⇌ Co(*s*) + 2OH^{-}	−0.746		−1.02
Copper			
Cu^{+} + e^{-} ⇌ Cu(*s*)	0.518		−0.754
Cu^{2+} + 2e^{-} ⇌ Cu(*s*)	0.339		0.011
Cu^{2+} + e^{-} ⇌ Cu^{+}	0.161		0.776
CuCl(*s*) + e^{-} ⇌ Cu(*s*) + Cl^{-}	0.137		
$Cu(IO_3)_2$(*s*) + 2e^{-} ⇌ Cu(*s*) + 2IO_3^{-}	−0.079		
Cu(ethylenediamine)$_2^{+}$ + e^{-} ⇌ Cu(*s*) + 2 ethylenediamine	−0.119		
CuI(*s*) + e^{-} ⇌ Cu(*s*) + I^{-}	−0.185		
Cu(EDTA)$^{2-}$ + 2e^{-} ⇌ Cu(*s*) + EDTA^{4-}	−0.216		
$Cu(OH)_2$(*s*) + 2e^{-} ⇌ Cu(*s*) + 2OH^{-}	−0.222		
$Cu(CN)_2^{-}$ + e^{-} ⇌ Cu(*s*) + 2CN^{-}	−0.429		
CuCN(*s*) + e^{-} ⇌ Cu(*s*) + CN^{-}	−0.639		

(Continued)

Reaction	$E°$ (volts)	$dE°/dT$ (mV/K)
Dysprosium		
$Dy^{3+} + 3e^- \rightleftharpoons Dy(s)$	−2.295	0.373
Erbium		
$Er^{3+} + 3e^- \rightleftharpoons Er(s)$	−2.331	0.388
Europium		
$Eu^{3+} + e^- \rightleftharpoons Eu^{2+}$	−0.35	1.53
$Eu^{3+} + 3e^- \rightleftharpoons Eu(s)$	−1.991	0.338
$Eu^{2+} + 2e^- \rightleftharpoons Eu(s)$	−2.812	−0.26
Fluorine		
$F_2(g) + 2e^- \rightleftharpoons 2F^-$	2.890	−1.870
$F_2O(g) + 2H^+ + 4e^- \rightleftharpoons 2F^- + H_2O$	2.168	−1.208
Gadolinium		
$Gd^{3+} + 3e^- \rightleftharpoons Gd(s)$	−2.279	0.315
Gallium		
$Ga^{3+} + 3e^- \rightleftharpoons Ga(s)$	−0.549	0.61
$GaOOH(s) + H_2O + 3e^- \rightleftharpoons Ga(s) + 3OH^-$	−1.320	−1.08
Germanium		
$Ge^{2+} + 2e^- \rightleftharpoons Ge(s)$	0.1	
$H_4GeO_4 + 4H^+ + 4e^- \rightleftharpoons Ge(s) + 4H_2O$	−0.039	−0.429
Gold		
$Au^+ + e^- \rightleftharpoons Au(s)$	1.69	−1.1
$Au^{3+} + 2e^- \rightleftharpoons Au^+$	1.41	
$AuCl_2^- + e^- \rightleftharpoons Au(s) + 2Cl^-$	1.154	
$AuCl_4^- + 2e^- \rightleftharpoons AuCl_2^- + 2Cl^-$	0.926	
Hafnium		
$Hf^{4+} + 4e^- \rightleftharpoons Hf(s)$	−1.55	0.68
$HfO_2(s) + 4H^+ + 4e^- \rightleftharpoons Hf(s) + 2H_2O$	−1.591	−0.355
Holmium		
$Ho^{3+} + 3e^- \rightleftharpoons Ho(s)$	−2.33	0.371
Hydrogen		
$2H^+ + 2e^- \rightleftharpoons H_2(g)$	0.000 0	0
$H_2O + e^- \rightleftharpoons \frac{1}{2}H_2(g) + OH^-$	−0.828 0	−0.836 0
Indium		
$In^{3+} + 3e^- + Hg \rightleftharpoons In(in\ Hg)$	−0.313	
$In^{3+} + 3e^- \rightleftharpoons In(s)$	−0.338	0.42
$In^{3+} + 2e^- \rightleftharpoons In^+$	−0.444	
$In(OH)_3(s) + 3e^- \rightleftharpoons In(s) + 3OH^-$	−0.99	−0.95
Iodine		
$IO_4^- + 2H^+ + 2e^- \rightleftharpoons IO_3^- + H_2O$	1.589	−0.85
$H_5IO_6 + 2H^+ + 2e^- \rightleftharpoons HIO_3 + 3H_2O$	1.567	−0.12
$HOI + H^+ + e^- \rightleftharpoons \frac{1}{2}I_2(s) + H_2O$	1.430	−0.339
$ICl_3(s) + 3e^- \rightleftharpoons \frac{1}{2}I_2(s) + 3Cl^-$	1.28	
$ICl(s) + e^- \rightleftharpoons \frac{1}{2}I_2(s) + Cl^-$	1.22	
$IO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}I_2(s) + 3H_2O$	1.210	−0.367
$IO_3^- + 5H^+ + 4e^- \rightleftharpoons HOI + 2H_2O$	1.154	−0.374
$I_2(aq) + 2e^- \rightleftharpoons 2I^-$	0.620	−0.234
$I_2(s) + 2e^- \rightleftharpoons 2I^-$	0.535	−0.125
$I_3^- + 2e^- \rightleftharpoons 3I^-$	0.535	−0.186
$IO_3^- + 3H_2O + 6e^- \rightleftharpoons I^- + 6OH^-$	0.269	−1.163
Iridium		
$IrCl_6^{2-} + e^- \rightleftharpoons IrCl_6^{3-}$	1.026 1 F HCl	
$IrBr_6^{2-} + e^- \rightleftharpoons IrBr_6^{3-}$	0.947 2 F NaBr	
$IrCl_6^{2-} + 4e^- \rightleftharpoons Ir(s) + 6Cl^-$	0.835	
$IrO_2(s) + 4H^+ + 4e^- \rightleftharpoons Ir(s) + 2H_2O$	0.73	−0.36
$IrI_6^{2-} + e^- \rightleftharpoons IrI_6^{3-}$	0.485 1 F KI	
Iron		
$Fe(phenanthroline)_3^{3+} + e^- \rightleftharpoons Fe(phenanthroline)_3^{2+}$	1.147	
$Fe(bipyridyl)_3^{3+} + e^- \rightleftharpoons Fe(bipyridyl)_3^{2+}$	1.120	
$FeOH^{2+} + H^+ + e^- \rightleftharpoons Fe^{2+} + H_2O$	0.900	0.096
$FeO_4^{2-} + 3H_2O + 3e^- \rightleftharpoons FeOOH(s) + 5OH^-$	0.80	−1.59
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	0.771	1.175
	0.732 1 F HCl	
	0.767 1 F $HClO_4$	
	0.746 1 F HNO_3	

Reaction	E° (volts)	dE°/dT (mV/K)
$FeOOH(s) + 3H^+ + e^- \rightleftharpoons Fe^{2+} + 2H_2O$	0.74	−1.05
$Ferricinium^+ + e^- \rightleftharpoons ferrocene$	0.400	
$Fe(CN)_6^{3-} + e^- \rightleftharpoons Fe(CN)_6^{4-}$	0.356	
$Fe(glutamate)^{3+} + e^- \rightleftharpoons Fe(glutamate)^{2+}$	0.240	
$FeOH^+ + H^+ + 2e^- \rightleftharpoons Fe(s) + H_2O$	−0.16	0.07
$Fe^{2+} + 2e^- \rightleftharpoons Fe(s)$	−0.44	0.07
$FeCO_3(s) + 2e^- \rightleftharpoons Fe(s) + CO_3^{2-}$	−0.756	−1.293
Lanthanum		
$La^{3+} + 3e^- \rightleftharpoons La(s)$	−2.379	0.242
$La(succinate)^+ + 3e^- \rightleftharpoons La(s) + succinate^{2-}$	−2.601	
Lead		
$Pb^{4+} + 2e^- \rightleftharpoons Pb^{2+}$	1.69 1 F HNO_3	
$PbO_2(s) + 4H^+ + SO_4^{2-} + 2e^- \rightleftharpoons PbSO_4(s) + 2H_2O$	1.685	
$PbO_2(s) + 4H^+ + 2e^- \rightleftharpoons Pb^{2+} + 2H_2O$	1.458	−0.253
$3PbO_2(s) + 2H_2O + 4e^- \rightleftharpoons Pb_3O_4(s) + 4OH^-$	0.269	−1.136
$Pb_3O_4(s) + H_2O + 2e^- \rightleftharpoons 3PbO(s, red) + 2OH^-$	0.224	−1.211
$Pb_3O_4(s) + H_2O + 2e^- \rightleftharpoons 3PbO(s, yellow) + 2OH^-$	0.207	−1.177
$Pb^{2+} + 2e^- \rightleftharpoons Pb(s)$	−0.126	−0.395
$PbF_2(s) + 2e^- \rightleftharpoons Pb(s) + 2F^-$	−0.350	
$PbSO_4(s) + 2e^- \rightleftharpoons Pb(s) + SO_4^{2-}$	−0.355	
Lithium		
$Li^+ + e^- + Hg \rightleftharpoons Li(in\ Hg)$	−2.195	
$Li^+ + e^- \rightleftharpoons Li(s)$	−3.040	−0.514
Lutetium		
$Lu^{3+} + 3e^- \rightleftharpoons Lu(s)$	−2.28	0.412
Magnesium		
$Mg^{2+} + 2e^- + Hg \rightleftharpoons Mg(in\ Hg)$	−1.980	
$Mg(OH)^+ + H^+ + 2e^- \rightleftharpoons Mg(s) + H_2O$	−2.022	0.25
$Mg^{2+} + 2e^- \rightleftharpoons Mg(s)$	−2.360	0.199
$Mg(C_2O_4)(s) + 2e^- \rightleftharpoons Mg(s) + C_2O_4^{2-}$	−2.493	
$Mg(OH)_2(s) + 2e^- \rightleftharpoons Mg(s) + 2OH^-$	−2.690	−0.946
Manganese		
$MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2(s) + 2H_2O$	1.692	−0.671
$Mn^{3+} + e^- \rightleftharpoons Mn^{2+}$	1.56	1.8
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	1.507	−0.646
$Mn_2O_3(s) + 6H^+ + 2e^- \rightleftharpoons 2Mn^{2+} + 3H_2O$	1.485	−0.926
$MnO_2(s) + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	1.230	−0.609
$Mn(EDTA)^- + e^- \rightleftharpoons Mn(EDTA)^{2-}$	0.825	−1.10
$MnO_4^- + e^- \rightleftharpoons MnO_4^{2-}$	0.56	−2.05
$3Mn_2O_3(s) + H_2O + 2e^- \rightleftharpoons 2Mn_3O_4(s) + 2OH^-$	0.002	−1.256
$Mn_3O_4(s) + 4H_2O + 2e^- \rightleftharpoons 3Mn(OH)_2(s) + 2OH^-$	−0.352	−1.61
$Mn^{2+} + 2e^- \rightleftharpoons Mn(s)$	−1.182	−1.129
$Mn(OH)_2(s) + 2e^- \rightleftharpoons Mn(s) + 2OH^-$	−1.565	−1.10
Mercury		
$2Hg^{2+} + 2e^- \rightleftharpoons Hg_2^{2+}$	0.908	0.095
$Hg^{2+} + 2e^- \rightleftharpoons Hg(l)$	0.852	−0.116
$Hg_2^{2+} + 2e^- \rightleftharpoons 2Hg(l)$	0.796	−0.327
$Hg_2SO_4(s) + 2e^- \rightleftharpoons 2Hg(l) + SO_4^{2-}$	0.614	
$Hg_2Cl_2(s) + 2e^- \rightleftharpoons 2Hg(l) + 2Cl^-$	0.268 0.241 (saturated calomel electrode)	
$Hg(OH)_3^- + 2e^- \rightleftharpoons Hg(l) + 3OH^-$	0.231	
$Hg(OH)_2 + 2e^- \rightleftharpoons Hg(l) + 2OH^-$	0.206	−1.24
$Hg_2Br_2(s) + 2e^- \rightleftharpoons 2Hg(l) + 2Br^-$	0.140	
$HgO(s, yellow) + H_2O + 2e^- \rightleftharpoons Hg(l) + 2OH^-$	0.098 3	−1.125
$HgO(s, red) + H_2O + 2e^- \rightleftharpoons Hg(l) + 2OH^-$	0.097 7	−1.120 6
Molybdenum		
$MoO_4^{2-} + 2H_2O + 2e^- \rightleftharpoons MoO_2(s) + 4OH^-$	−0.818	−1.69
$MoO_4^{2-} + 4H_2O + 6e^- \rightleftharpoons Mo(s) + 8OH^-$	−0.926	−1.36
$MoO_2(s) + 2H_2O + 4e^- \rightleftharpoons Mo(s) + 4OH^-$	−0.980	−1.196
Neodymium		
$Nd^{3+} + 3e^- \rightleftharpoons Nd(s)$	−2.323	0.282
Neptunium		
$NpO_3^+ + 2H^+ + e^- \rightleftharpoons NpO_2^{2+} + H_2O$	2.04	
$NpO_2^{2+} + e^- \rightleftharpoons NpO_2^+$	1.236	0.058

(Continued)

Reaction	E° (volts)	dE°/dT (mV/K)
$NpO_2^+ + 4H^+ + e^- \rightleftharpoons Np^{4+} + 2H_2O$	0.567	−3.30
$Np^{4+} + e^- \rightleftharpoons Np^{3+}$	0.157	1.53
$Np^{3+} + 3e^- \rightleftharpoons Np(s)$	−1.768	0.18
Nickel		
$NiOOH(s) + 3H^+ + e^- \rightleftharpoons Ni^{2+} + 2H_2O$	2.05	−1.17
$Ni^{2+} + 2e^- \rightleftharpoons Ni(s)$	−0.236	0.146
$Ni(CN)_4^{2-} + e^- \rightleftharpoons Ni(CN)_3^{2-} + CN^-$	−0.401	
$Ni(OH)_2(s) + 2e^- \rightleftharpoons Ni(s) + 2OH^-$	−0.714	−1.02
Niobium		
$\frac{1}{2}Nb_2O_5(s) + H^+ + e^- \rightleftharpoons NbO_2(s) + \frac{1}{2}H_2O$	−0.248	−0.460
$\frac{1}{2}Nb_2O_5(s) + 5H^+ + 5e^- \rightleftharpoons Nb(s) + \frac{5}{2}H_2O$	−0.601	−0.381
$NbO_2(s) + 2H^+ + 2e^- \rightleftharpoons NbO(s) + H_2O$	−0.646	−0.347
$NbO_2(s) + 4H^+ + 4e^- \rightleftharpoons Nb(s) + 2H_2O$	−0.690	−0.361
Nitrogen		
$HN_3 + 3H^+ + 2e^- \rightleftharpoons N_2(g) + NH_4^+$	2.079	0.147
$N_2O(g) + 2H^+ + 2e^- \rightleftharpoons N_2(g) + H_2O$	1.769	−0.461
$2NO(g) + 2H^+ + 2e^- \rightleftharpoons N_2O(g) + H_2O$	1.587	−1.359
$NO^+ + e^- \rightleftharpoons NO(g)$	1.46	
$2NH_3OH^+ + H^+ + 2e^- \rightleftharpoons N_2H_5^+ + 2H_2O$	1.40	−0.60
$NH_3OH^+ + 2H^+ + 2e^- \rightleftharpoons NH_4^+ + H_2O$	1.33	−0.44
$N_2H_5^+ + 3H^+ + 2e^- \rightleftharpoons 2NH_4^+$	1.250	−0.28
$HNO_2 + H^+ + e^- \rightleftharpoons NO(g) + H_2O$	0.984	0.649
$NO_3^- + 4H^+ + 3e^- \rightleftharpoons NO(g) + 2H_2O$	0.955	0.028
$NO_3^- + 3H^+ + 2e^- \rightleftharpoons HNO_2 + H_2O$	0.940	−0.282
$NO_3^- + 2H^+ + e^- \rightleftharpoons \frac{1}{2}N_2O_4(g) + H_2O$	0.798	0.107
$N_2(g) + 8H^+ + 6e^- \rightleftharpoons 2NH_4^+$	0.274	−0.616
$N_2(g) + 5H^+ + 4e^- \rightleftharpoons N_2H_5^+$	−0.214	−0.78
$N_2(g) + 2H_2O + 4H^+ + 2e^- \rightleftharpoons 2NH_3OH^+$	−1.83	−0.96
$\frac{3}{2}N_2(g) + H^+ + e^- \rightleftharpoons HN_3$	−3.334	−2.141
Osmium		
$OsO_4(s) + 8H^+ + 8e^- \rightleftharpoons Os(s) + 4H_2O$	0.834	−0.458
$OsCl_6^{2-} + e^- \rightleftharpoons OsCl_6^{3-}$	0.85 1 F HCl	
Oxygen		
$OH + H^+ + e^- \rightleftharpoons H_2O$	2.56	−1.0
$O(g) + 2H^+ + 2e^- \rightleftharpoons H_2O$	2.430 1	−1.148 4
$O_3(g) + 2H^+ + 2e^- \rightleftharpoons O_2(g) + H_2O$	2.075	−0.489
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	1.763	−0.698
$HO_2 + H^+ + e^- \rightleftharpoons H_2O_2$	1.44	−0.7
$\frac{1}{2}O_2(g) + 2H^+ + 2e^- \rightleftharpoons H_2O$	1.229 1	−0.845 6
$O_2(g) + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	0.695	−0.993
$O_2(g) + H^+ + e^- \rightleftharpoons HO_2$	−0.05	−1.3
Palladium		
$Pd^{2+} + 2e^- \rightleftharpoons Pd(s)$	0.915	0.12
$PdO(s) + 2H^+ + 2e^- \rightleftharpoons Pd(s) + H_2O$	0.79	−0.33
$PdCl_6^{4-} + 2e^- \rightleftharpoons Pd(s) + 6Cl^-$	0.615	
$PdO_2(s) + H_2O + 2e^- \rightleftharpoons PdO(s) + 2OH^-$	0.64	−1.2
Phosphorus		
$\frac{1}{4}P_4(s, \text{white}) + 3H^+ + 3e^- \rightleftharpoons PH_3(g)$	−0.046	−0.093
$\frac{1}{4}P_4(s, \text{red}) + 3H^+ + 3e^- \rightleftharpoons PH_3(g)$	−0.088	−0.030
$H_3PO_4 + 2H^+ + 2e^- \rightleftharpoons H_3PO_3 + H_2O$	−0.30	−0.36
$H_3PO_4 + 5H^+ + 5e^- \rightleftharpoons \frac{1}{4}P_4(s, \text{white}) + 4H_2O$	−0.402	−0.340
$H_3PO_3 + 2H^+ + 2e^- \rightleftharpoons H_3PO_2 + H_2O$	−0.48	−0.37
$H_3PO_2 + H^+ + e^- \rightleftharpoons \frac{1}{4}P_4(s) + 2H_2O$	−0.51	
Platinum		
$Pt^{2+} + 2e^- \rightleftharpoons Pt(s)$	1.18	−0.05
$PtO_2(s) + 4H^+ + 4e^- \rightleftharpoons Pt(s) + 2H_2O$	0.92	−0.36
$PtCl_4^{2-} + 2e^- \rightleftharpoons Pt(s) + 4Cl^-$	0.755	
$PtCl_6^{2-} + 2e^- \rightleftharpoons PtCl_4^{2-} + 2Cl^-$	0.68	
Plutonium		
$PuO_2^+ + e^- \rightleftharpoons PuO_2(s)$	1.585	0.39
$PuO_2^{2+} + 4H^+ + 2e^- \rightleftharpoons Pu^{4+} + 2H_2O$	1.000	−1.615 1
$Pu^{4+} + e^- \rightleftharpoons Pu^{3+}$	1.006	1.441
$PuO_2^{2+} + e^- \rightleftharpoons PuO_2^+$	0.966	0.03
$PuO_2(s) + 4H^+ + 4e^- \rightleftharpoons Pu(s) + 2H_2O$	−1.369	−0.38
$Pu^{3+} + 3e^- \rightleftharpoons Pu(s)$	−1.978	0.23

Reaction	E° (volts)	dE°/dT (mV/K)
Potassium		
$K^+ + e^- + Hg \rightleftharpoons K(in\ Hg)$	−1.975	
$K^+ + e^- \rightleftharpoons K(s)$	−2.936	−1.074
Praseodymium		
$Pr^{4+} + e^- \rightleftharpoons Pr^{3+}$	3.2	1.4
$Pr^{3+} + 3e^- \rightleftharpoons Pr(s)$	−2.353	0.291
Promethium		
$Pm^{3+} + 3e^- \rightleftharpoons Pm(s)$	−2.30	0.29
Radium		
$Ra^{2+} + 2e^- \rightleftharpoons Ra(s)$	−2.80	−0.44
Rhenium		
$ReO_4^- + 2H^+ + e^- \rightleftharpoons ReO_3(s) + H_2O$	0.72	−1.17
$ReO_4^- + 4H^+ + 3e^- \rightleftharpoons ReO_2(s) + 2H_2O$	0.510	−0.70
Rhodium		
$Rh^{6+} + 3e^- \rightleftharpoons Rh^{3+}$	1.48 1 F $HClO_4$	
$Rh^{4+} + e^- \rightleftharpoons Rh^{3+}$	1.44 3 F H_2SO_4	
$RhCl_6^{2-} + e^- \rightleftharpoons RhCl_6^{3-}$	1.2	
$Rh^{3+} + 3e^- \rightleftharpoons Rh(s)$	0.76	0.4
$2Rh^{3+} + 2e^- \rightleftharpoons Rh_2^{4+}$	0.7	
$RhCl_6^{3-} + 3e^- \rightleftharpoons Rh(s) + 6Cl^-$	0.44	
Rubidium		
$Rb^+ + e^- + Hg \rightleftharpoons Rb(in\ Hg)$	−1.970	
$Rb^+ + e^- \rightleftharpoons Rb(s)$	−2.943	−1.140
Ruthenium		
$RuO_4^- + 6H^+ + 3e^- \rightleftharpoons Ru(OH)_2^{2+} + 2H_2O$	1.53	
$Ru(dipyridyl)_3^{3+} + e^- \rightleftharpoons Ru(dipyridyl)_3^{2+}$	1.29	
$RuO_4(s) + 8H^+ + 8e^- \rightleftharpoons Ru(s) + 4H_2O$	1.032	−0.467
$Ru^{2+} + 2e^- \rightleftharpoons Ru(s)$	0.8	
$Ru^{3+} + 3e^- \rightleftharpoons Ru(s)$	0.60	
$Ru^{3+} + e^- \rightleftharpoons Ru^{2+}$	0.24	
$Ru(NH_3)_6^{3+} + e^- \rightleftharpoons Ru(NH_3)_6^{2+}$	0.214	
Samarium		
$Sm^{3+} + 3e^- \rightleftharpoons Sm(s)$	−2.304	0.279
$Sm^{2+} + 2e^- \rightleftharpoons Sm(s)$	−2.68	−0.28
Scandium		
$Sc^{3+} + 3e^- \rightleftharpoons Sc(s)$	−2.09	0.41
Selenium		
$SeO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons H_2SeO_3 + H_2O$	1.150	0.483
$H_2SeO_3 + 4H^+ + 4e^- \rightleftharpoons Se(s) + 3H_2O$	0.739	−0.562
$Se(s) + 2H^+ + 2e^- \rightleftharpoons H_2Se(g)$	−0.082	0.238
$Se(s) + 2e^- \rightleftharpoons Se^{2-}$	−0.67	−1.2
Silicon		
$Si(s) + 4H^+ + 4e^- \rightleftharpoons SiH_4(g)$	−0.147	−0.196
$SiO_2(s, quartz) + 4H^+ + 4e^- \rightleftharpoons Si(s) + 2H_2O$	−0.990	−0.374
$SiF_6^{2-} + 4e^- \rightleftharpoons Si(s) + 6F^-$	−1.24	
Silver		
$Ag^{2+} + e^- \rightleftharpoons Ag^+$	{ 2.000 4 F $HClO_4$; 1.989; 1.929 4 F HNO_3 }	0.99
$Ag^{3+} + 2e^- \rightleftharpoons Ag^+$	1.9	
$AgO(s) + H^+ + e^- \rightleftharpoons \frac{1}{2}Ag_2O(s) + \frac{1}{2}H_2O$	1.40	
$Ag^+ + e^- \rightleftharpoons Ag(s)$	0.799 3	−0.989
$Ag_2C_2O_4(s) + 2e^- \rightleftharpoons 2Ag(s) + C_2O_4^{2-}$	0.465	
$AgN_3(s) + e^- \rightleftharpoons Ag(s) + N_3^-$	0.293	
$AgCl(s) + e^- \rightleftharpoons Ag(s) + Cl^-$	{ 0.222; 0.197 saturated KCl }	
$AgBr(s) + e^- \rightleftharpoons Ag(s) + Br^-$	0.071	
$Ag(S_2O_3)_2^{3-} + e^- \rightleftharpoons Ag(s) + 2S_2O_3^{2-}$	0.017	
$AgI(s) + e^- \rightleftharpoons Ag(s) + I^-$	−0.152	
$Ag_2S(s) + H^+ + 2e^- \rightleftharpoons 2Ag(s) + SH^-$	−0.272	
Sodium		
$Na^+ + e^- + Hg \rightleftharpoons Na(in\ Hg)$	−1.959	
$Na^+ + \frac{1}{2}H_2(g) + e^- \rightleftharpoons NaH(s)$	−2.367	−1.550
$Na^+ + e^- \rightleftharpoons Na(s)$	−2.714 3	−0.757

(Continued)

Reaction	E° (volts)		dE°/dT (mV/K)
Strontium			
$Sr^{2+} + 2e^- \rightleftharpoons Sr(s)$	−2.889		−0.237
Sulfur			
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	2.01		
$S_2O_6^{2-} + 4H^+ + 2e^- \rightleftharpoons 2H_2SO_3$	0.57		
$4SO_2 + 4H^+ + 6e^- \rightleftharpoons S_4O_6^{2-} + 2H_2O$	0.539		−1.11
$SO_2 + 4H^+ + 4e^- \rightleftharpoons S(s) + 2H_2O$	0.450		−0.652
$2H_2SO_3 + 2H^+ + 4e^- \rightleftharpoons S_2O_3^{2-} + 3H_2O$	0.40		
$S(s) + 2H^+ + 2e^- \rightleftharpoons H_2S(g)$	0.174		0.224
$S(s) + 2H^+ + 2e^- \rightleftharpoons H_2S(aq)$	0.144		−0.21
$S_4O_6^{2-} + 2H^+ + 2e^- \rightleftharpoons 2HS_2O_3^-$	0.10		−0.23
$5S(s) + 2e^- \rightleftharpoons S_5^{2-}$	−0.340		
$S(s) + 2e^- \rightleftharpoons S^{2-}$	−0.476		−0.925
$2S(s) + 2e^- \rightleftharpoons S_2^{2-}$	−0.50		−1.16
$2SO_3^{2-} + 3H_2O + 4e^- \rightleftharpoons S_2O_3^{2-} + 6OH^-$	−0.566		−1.06
$SO_3^{2-} + 3H_2O + 4e^- \rightleftharpoons S(s) + 6OH^-$	−0.659		−1.23
$SO_4^{2-} + 4H_2O + 6e^- \rightleftharpoons S(s) + 8OH^-$	−0.751		−1.288
$SO_4^{2-} + H_2O + 2e^- \rightleftharpoons SO_3^{2-} + 2OH^-$	−0.936		−1.41
$2SO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons S_2O_4^{2-} + 4OH^-$	−1.130		−0.85
$2SO_4^{2-} + 2H_2O + 2e^- \rightleftharpoons S_2O_6^{2-} + 4OH^-$	−1.71		−1.00
Tantalum			
$Ta_2O_5(s) + 10H^+ + 10e^- \rightleftharpoons 2Ta(s) + 5H_2O$	−0.752		−0.377
Technetium			
$TcO_4^- + 2H_2O + 3e^- \rightleftharpoons TcO_2(s) + 4OH^-$	−0.366		−1.82
$TcO_4^- + 4H_2O + 7e^- \rightleftharpoons Tc(s) + 8OH^-$	−0.474		−1.46
Tellurium			
$TeO_3^{2-} + 3H_2O + 4e^- \rightleftharpoons Te(s) + 6OH^-$	−0.47		−1.39
$2Te(s) + 2e^- \rightleftharpoons Te_2^{2-}$	−0.84		
$Te(s) + 2e^- \rightleftharpoons Te^{2-}$	−0.90		−1.0
Terbium			
$Tb^{4+} + e^- \rightleftharpoons Tb^{3+}$	3.1		1.5
$Tb^{3+} + 3e^- \rightleftharpoons Tb(s)$	−2.28		0.350
Thallium			
$Tl^{3+} + 2e^- \rightleftharpoons Tl^+$	1.280		0.97
	0.77	1 F HCl	
	1.22	1 F H_2SO_4	
	1.23	1 F HNO_3	
	1.26	1 F $HClO_4$	
$Tl^+ + e^- + Hg \rightleftharpoons Tl(in\ Hg)$	−0.294		
$Tl^+ + e^- \rightleftharpoons Tl(s)$	−0.336		−1.312
$TlCl(s) + e^- \rightleftharpoons Tl(s) + Cl^-$	−0.557		
Thorium			
$Th^{4+} + 4e^- \rightleftharpoons Th(s)$	−1.826		0.557
Thulium			
$Tm^{3+} + 3e^- \rightleftharpoons Tm(s)$	−2.319		0.394
Tin			
$Sn(OH)_3^+ + 3H^+ + 2e^- \rightleftharpoons Sn^{2+} + 3H_2O$	0.142		
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	0.139	1 F HCl	
$SnO_2(s) + 4H^+ + 2e^- \rightleftharpoons Sn^{2+} + 2H_2O$	−0.094		−0.31
$Sn^{2+} + 2e^- \rightleftharpoons Sn(s)$	−0.141		−0.32
$SnF_6^{2-} + 4e^- \rightleftharpoons Sn(s) + 6F^-$	−0.25		
$Sn(OH)_6^{2-} + 2e^- \rightleftharpoons Sn(OH)_3^- + 3OH^-$	−0.93		
$Sn(s) + 4H_2O + 4e^- \rightleftharpoons SnH_4(g) + 4OH^-$	−1.316		−1.057
$SnO_2(s) + H_2O + 2e^- \rightleftharpoons SnO(s) + 2OH^-$	−0.961		−1.129
Titanium			
$TiO^{2+} + 2H^+ + e^- \rightleftharpoons Ti^{3+} + H_2O$	0.1		−0.6
$Ti^{3+} + e^- \rightleftharpoons Ti^{2+}$	−0.9		1.5
$TiO_2(s) + 4H^+ + 4e^- \rightleftharpoons Ti(s) + 2H_2O$	−1.076		0.365
$TiF_6^{2-} + 4e^- \rightleftharpoons Ti(s) + 6F^-$	−1.191		
$Ti^{2+} + 2e^- \rightleftharpoons Ti(s)$	−1.60		−0.16
Tungsten			
$W(CN)_8^{3-} + e^- \rightleftharpoons W(CN)_8^{4-}$	0.457		
$W^{6+} + e^- \rightleftharpoons W^{5+}$	0.26	12 F HCl	
$WO_3(s) + 6H^+ + 6e^- \rightleftharpoons W(s) + 3H_2O$	−0.091		−0.389

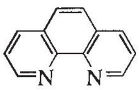
Reaction	E° (volts)		dE°/dT (mV/K)
$W^{5+} + e^- \rightleftharpoons W^{4+}$	−0.3	12 F HCl	
$WO_2(s) + 2H_2O + 4e^- \rightleftharpoons W(s) + 4OH^-$	−0.982		−1.197
$WO_4^{2-} + 4H_2O + 6e^- \rightleftharpoons W(s) + 8OH^-$	−1.060		−1.36
Uranium			
$UO_2^+ + 4H^+ + e^- \rightleftharpoons U^{4+} + 2H_2O$	0.39		−3.4
$UO_2^{2+} + 4H^+ + 2e^- \rightleftharpoons U^{4+} + 2H_2O$	0.273		−1.582
$UO_2^{2+} + e^- \rightleftharpoons UO_2^+$	0.16		0.2
$U^{4+} + e^- \rightleftharpoons U^{3+}$	−0.577		1.61
$U^{3+} + 3e^- \rightleftharpoons U(s)$	−1.642		0.16
Vanadium			
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	1.001		−0.901
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	0.337		−1.6
$V^{3+} + e^- \rightleftharpoons V^{2+}$	−0.255		1.5
$V^{2+} + 2e^- \rightleftharpoons V(s)$	−1.125		−0.11
Xenon			
$H_4XeO_6 + 2H^+ + 2e^- \rightleftharpoons XeO_3 + 3H_2O$	2.38		0.0
$XeF_2 + 2H^+ + 2e^- \rightleftharpoons Xe(g) + 2HF$	2.2		
$XeO_3 + 6H^+ + 6e^- \rightleftharpoons Xe(g) + 3H_2O$	2.1		−0.34
Ytterbium			
$Yb^{3+} + 3e^- \rightleftharpoons Yb(s)$	−2.19		0.363
$Yb^{2+} + 2e^- \rightleftharpoons Yb(s)$	−2.76		−0.16
Yttrium			
$Y^{3+} + 3e^- \rightleftharpoons Y(s)$	−2.38		0.034
Zinc			
$ZnOH^+ + H^+ + 2e^- \rightleftharpoons Zn(s) + H_2O$	−0.497		0.03
$Zn^{2+} + 2e^- \rightleftharpoons Zn(s)$	−0.762		0.119
$Zn^{2+} + 2e^- + Hg \rightleftharpoons Zn(in\ Hg)$	−0.801		
$Zn(NH_3)_4^{2+} + 2e^- \rightleftharpoons Zn(s) + 4NH_3$	−1.04		
$ZnCO_3(s) + 2e^- \rightleftharpoons Zn(s) + CO_3^{2-}$	−1.06		
$Zn(OH)_3^- + 2e^- \rightleftharpoons Zn(s) + 3OH^-$	−1.183		
$Zn(OH)_4^{2-} + 2e^- \rightleftharpoons Zn(s) + 4OH^-$	−1.199		
$Zn(OH)_2(s) + 2e^- \rightleftharpoons Zn(s) + 2OH^-$	−1.249		−0.999
$ZnO(s) + H_2O + 2e^- \rightleftharpoons Zn(s) + 2OH^-$	−1.260		−1.160
$ZnS(s) + 2e^- \rightleftharpoons Zn(s) + S^{2-}$	−1.405		
Zirconium			
$Zr^{4+} + 4e^- \rightleftharpoons Zr(s)$	−1.45		0.67
$ZrO_2(s) + 4H^+ + 4e^- \rightleftharpoons Zr(s) + 2H_2O$	−1.473		−0.344

APPENDIX I

Formation Constants*

Reacting ions	log β_1	log β_2	log β_3	log β_4	log β_5	log β_6	Temperature (°C)	Ionic strength (μ, M)
Acetate, $CH_3CO_2^-$								
Ag^+	0.73	0.64					25	0
Ca^{2+}	1.24						25	0
Cd^{2+}	1.93	3.15					25	0
Cu^{2+}	2.23	3.63					25	0
Fe^{2+}	1.82						25	0.5
Fe^{3+}	3.38	7.1	9.7				20	0.1
Mg^{2+}	1.25						25	0
Mn^{2+}	1.40						25	0
Na^+	−0.18						25	0
Ni^{2+}	1.43						25	0
Zn^{2+}	1.28	2.09					20	0.1
Ammonia, NH_3								
Ag^+	3.31	7.23					25	0
Cd^{2+}	2.51	4.47	5.77	6.56			30	0
Co^{2+}	1.99	3.50	4.43	5.07	5.13	4.39	30	0
Cu^{2+}	3.99	7.33	10.06	12.03			30	0
Hg^{2+}	8.8	17.5	18.50	19.28			22	2
Ni^{2+}	2.67	4.79	6.40	7.47	8.10	8.01	30	0
Zn^{2+}	2.18	4.43	6.74	8.70			30	0
Cyanide, CN^-								
Ag^+		20	21				20	0
Cd^{2+}	5.18	9.60	13.92	17.11			25	?
Cu^+		24	28.6	30.3			25	0
Ni^{2+}				30			25	0
Tl^{3+}	13.21	26.50	35.17	42.61			25	4
Zn^{2+}		11.07	16.05	19.62			25	0
Ethylenediamine (1,2-diaminoethane), $H_2NCH_2CH_2NH_2$								
Ag^+	4.70	7.70	9.7				20	0.1
Cd^{2+}	5.69	10.36	12.80				25	0.5
Cu^{2+}	10.66	19.99					20	0
Hg^{2+}	14.3	23.3	23.2				25	0.1
Ni^{2+}	7.52	13.84	18.33				20	0
Zn^{2+}	5.77	10.83	14.11				20	0
Hydroxide, OH^-								
Ag^+	2.0	3.99					25	0
Al^{3+}	9.00	17.9	25.2	33.3			25	0
	log β_{22} = 20.3 log β_{43} = 42.1							
Ba^{2+}	0.64						25	0
Bi^{3+}	12.9	23.5	33.0	34.8			25	0
	log $\beta_{12\,6}$ = 165.3 (μ = 1)							
Be^{2+}	8.6	14.4	18.8	18.6			25	0
	log β_{12} = 10.82 (μ = 0.1) log β_{33} = 32.54 (μ = 0.1) log β_{65} = 66.24 (μ = 3) log β_{86} = 85 (μ = 0)							
Ca^{2+}	1.30						25	0
Cd^{2+}	3.9	7.7	10.3 (μ = 3)	12.0 (μ = 3)			25	0
	log β_{12} = 4.6 log β_{44} = 23.2							
Ce^{3+}	4.9						25	3
	log β_{22} = 12.4 log β_{53} = 35.1							
Co^{2+}	4.3	9.2	10.5	9.7			25	0
	log β_{12} = 3 log β_{44} = 25.5							
Co^{3+}	13.52						25	3

**The overall (cumulative) formation constant.* β_n, *is the equilibrium constant for the reaction* $M + nL \rightleftharpoons ML_n$: $\beta_n = [ML_n]/([M][L]^n)$. β_n *is related to stepwise formation constants* (K_i) *by* $\beta_n = K_1K_2 \ldots K_n$ *(Box 6-2).* β_{nm} *is the cumulative formation constant for the reaction* $mM + nL \rightleftharpoons M_mL_n$: $\beta_{nm} = [M_mL_n]/([M]^m[L]^n)$. *The subscript n refers to the ligand and m refers to the metal. Data from L. G. Sillén and A. E. Martell, Stability Constants of Metal-Ion Complexes (London: The Chemical Society. Special Publications No. 17 and 25, 1964 and 1971); and A. E. Martell, R. M. Smith, and R. J. Motekaitis, NIST Critical Stability Constants of Metal Complexes Database 46 (Gaithersburg, MD: National Institute of Standards and Technology, 2001).*

Reacting ions	log β_1	log β_2	log β_3	log β_4	log β_5	log β_6	Temperature (°C)	Ionic strength (μ, M)
Co^{2+}	10.0	13.9					20	0.1
Cu^{2+}	11.5	14.8					20	0.1
Fe^{3+}	15.91	24.61					20	0.1
Ga^{3+}	13.6	21.8					20	0.1
In^{3+}	16.9						20	0.1
Mg^{2+}	5.46						20	0.1
Mn^{2+}	7.4						20	0.1
Ni^{2+}	11.54						20	0.1
Pb^{2+}	11.47						20	0.1
Tl^{+}	4.75						20	0.1
Zn^{2+}	10.44						20	0.1
Oxalate, $^{-}O_2CCO_2^{-}$								
Al^{3+}			15.60				20	0.1
Ba^{2+}	2.31						18	0
Ca^{2+}	1.66	2.69					25	1
Cd^{2+}	3.71						20	0.1
Co^{2+}	4.69	7.15					25	0
Cu^{2+}	6.23	10.27					25	0
Fe^{3+}	7.54	14.59	20.00				?	0.5
Ni^{2+}	5.16	6.5					25	0
Zn^{2+}	4.85	7.6					25	0
1,10-Phenanthroline, 								
Ag^{+}	5.02	12.07					25	0.1
Ca^{2+}	0.7						20	0.1
Cd^{2+}	5.17	10.00	14.25				25	0.1
Co^{2+}	7.02	13.72	20.10				25	0.1
Cu^{2+}	8.82	15.39	20.41				25	0.1
Fe^{2+}	5.86	11.11	21.14				25	0.1
Fe^{3+}			14.10				25	0.1
Hg^{2+}		19.65	23.4				20	0.1
Mn^{2+}	4.50	8.65	12.70				25	0.1
Ni^{2+}	8.0	16.0	23.9				25	0.1
Zn^{2+}	6.30	11.95	17.05				25	0.1

APPENDIX J

Logarithm of the Formation Constant for the Reaction $M(aq) + L(aq) \rightleftharpoons ML(aq)$*

M	L: F^-	Cl^-	Br^-	I^-	NO_3^-	ClO_4^-	IO_3^-	SCN^-	SO_4^{2-}	CO_3^{2-}
Li^+	0.23	—	—	—	—	—	—	—	0.64	—
Na^+	−0.2	−0.5	—	—	−0.55	−0.7	−0.4	—	0.72	1.27
K^+	−1.2[a]	−0.5	—	−0.4	−0.19	−0.03	−0.27	—	0.85	—
Rb^+	—	−0.4	—	0.04	−0.08	0.15	−0.19	—	0.60	—
Cs^+	—	−0.2	0.03	−0.03	−0.02	0.23	−0.11	—	0.3	—
Ag^+	0.4	3.31	4.6	6.6	−0.1	−0.1	0.63	4.8	1.3	—
$(CH_3)_4N^+$	—	0.04	0.16	0.31	—	0.27	—	—	—	—
Mg^{2+}	2.05	0.6	−1.4[d]	—	—	—	0.72	−0.9[d]	2.23	2.92
Ca^{2+}	0.63	0.2[b]	—	—	0.5	—	0.89	—	2.36	3.20
Sr^{2+}	0.14	−0.22[a]	—	—	0.6	—	1.00	—	2.2	2.81
Ba^{2+}	−0.20	−0.44[a]	—	—	0.7	—	1.10	—	2.2	2.71
Zn^{2+}	1.3	0.4	−0.07	−1.5[d]	0.4	—	—	1.33	2.34	4.76
Cd^{2+}	1.2	1.98	2.15	2.28	0.5	—	0.51[a]	1.98	2.46	3.49[b]
Hg_2^{2+}	—	—	—	—	0.08[f]	—	—	—	1.30[f]	—
Sn^{2+}	—	1.64	1.16	0.70[e]	0.44[a]	—	—	0.83[a]	—	—
Y^{3+}	4.81	−0.1[a]	−0.15[a]	—	—	—	—	−0.07[f]	3.47	8.2
La^{3+}	3.60	−0.1[a]	—	—	0.1[a]	—	—	0.12[a]	3.64	5.6[d]
In^{3+}	4.65	2.32[c]	2.01[c]	1.64[c]	0.18	—	—	3.15	1.85[a]	—

**Unless otherwise indicated, conditions are 25°C and $\mu = 0$. From A. E. Martell, R. M. Smith, and R. J. Motekaitis, NIST Critical Stability Constants of Metal Complexes Database 46 (Gaithersburg, MD: National Institute of Standards and Technology, 2001).*

a. $\mu = 1$ M; b. $\mu = 0.1$ M; c. $\mu = 0.7$ M; d. $\mu = 3$ M; e. $\mu = 4$ M; f. $\mu = 0.5$ M.

APPENDIX K

Analytical Standards

The table in this appendix recommends primary standards for many elements. An *elemental assay standard* must contain a known amount of the desired element. A *matrix matching standard* must contain extremely low concentrations of undesired impurities, such as the analyte. If you want to prepare 10 ppm Fe in 10% aqueous NaCl, the NaCl must not contain significant Fe impurity, because the impurity would then have a higher concentration than the deliberately added Fe.

Rather than using compounds in the table, many people purchase certified solutions whose concentrations are traceable to standards from the National Institute of Standards and Technology (NIST or other national institutes of standards). By *NIST traceable,* we mean that the solution has been prepared from a standard material certified by NIST or that it has been compared with an NIST standard by a reliable analytical procedure.

Manufacturers frequently indicate elemental purity by some number of 9s. This deceptive nomenclature is based on the measurement of certain impurities. For example, 99.999% (five 9s) pure Al is certified to contain ≤0.001% *metallic* impurities, based on the analysis of other metals present. However, C, H, N, and O are not measured. The Al might contain 0.1% Al_2O_3 and still be "five 9s pure." For the most accurate work, the dissolved gas content in solid elements may also be a source of error.

Carbonates, oxides, and other compounds may not possess the expected stoichiometry. For example, TbO_2 will have a high Tb content if some Tb_4O_7 is present. Ignition in an O_2 atmosphere may be helpful, but the final stoichiometry is never guaranteed. Carbonates may contain traces of bicarbonate, oxide, and hydroxide. Firing in a CO_2 atmosphere may improve the stoichiometry. Sulfates may contain some HSO_4^-. Some chemical analysis may be required to ensure that you know what you are really working with.

Most metal standards dissolve in 6 M HCl or HNO_3 or a mixture of the two, possibly with heating. Frothing accompanies dissolution of metals or carbonates in acid, so vessels should be loosely covered by a watchglass or Teflon lid to prevent loss of material. Concentrated HNO_3 (16 M) may *passivate* some metals, forming an insoluble oxide coat that prevents dissolution. If you have a choice between using a bulk element or a powder as standards, the bulk form is preferred because it has a smaller surface area on which oxides can form and impurities can be adsorbed. After a pure metal to be used as a standard is cut, it should be etched ("pickled") in a dilute solution of the acid in which it will be dissolved to remove surface oxides and contamination from the cutter. The metal is then washed well with water and dried in a vacuum desiccator.

Dilute solutions of metals are best prepared in Teflon or plastic vessels, because glass is an ion exchanger that can replace analyte species. Specially cleaned glass vials are commercially available for trace organic analysis. Volumetric dilutions are rarely more accurate than 0.1%, so gravimetric dilutions are required for greater accuracy. Of course, weights should be corrected for buoyancy with Equation 2-1. Evaporation of standard solutions is a source of error that is prevented if the mass of the reagent bottle is recorded after each use. If the mass changes between uses, the contents are evaporating.

Calibration standards

Element	Source[a]	Purity	Comments[b]
Li	SRM 924 (Li_2CO_3)	100.05 ± 0.02%	E; dry at 200°C for 4 h.
	Li_2CO_3	five–six 9s	M; purity calculated from impurities. Stoichiometry unknown.
Na	SRM 919 or 2201 (NaCl)	99.9%	E; dry for 24 h over $Mg(ClO_4)_2$.
	Na_2CO_3	three 9s	M; purity based on metallic impurities.
K	SRM 918 (KCl)	99.9%	E; dry for 24 h over $Mg(ClO_4)_2$.
	SRM 999 (KCl)	52.435 ± 0.004% K	E; ignite at 500°C for 4 h.
	K_2CO_3	five–six 9s	M; purity based on metallic impurities.
Rb	SRM 984 (RbCl)	99.90 ± 0.02%	E; hygroscopic. Dry for 24 h over $Mg(ClO_4)_2$.
	Rb_2CO_3		M
Cs	Cs_2CO_3		M
Be	metal	three 9s	E, M; purity based on metallic impurities.
Mg	SRM 929	100.1 ± 0.4%	E; magnesium gluconate clinical standard.
		5.403 ± 0.022% Mg	Dry for 24 h over $Mg(ClO_4)_2$.
	metal	five 9s	E; purity based on metallic impurities.
Ca	SRM 915 ($CaCO_3$)	three 9s	E; use without drying.
	$CaCO_3$	five 9s	E, M; dry at 200°C for 4 h in CO_2. User must determine stoichiometry.
Sr	SRM 987 ($SrCO_3$)	99.8%	E; ignite to establish stoichiometry. Dry at 110°C for 1 h.
	$SrCO_3$	five 9s	M; up to 1% off stoichiometry. Ignite to establish stoichiometry. Dry at 200°C for 4 h.
Ba	$BaCO_3$	four–five 9s	M; dry at 200°C for 4 h.

Transition metals: Use pure metals (usually ≥four 9s) for elemental and matrix standards. Assays are based on impurities and do not include dissolved gases.

Lanthanides: Use pure metals (usually ≥four 9s) for elemental standards and oxides as matrix standards. Oxides may be difficult to dry and stoichiometry is not certain.

a. SRM is the National Institute of Standards and Technology designation for a Standard Reference Material.

b. E means elemental assay standard; M means matrix matching standard.

SOURCES: J. R. Moody, R. R. Greenberg, K. W. Pratt, and T. C. Rains, "Recommended Inorganic Chemicals for Calibration," Anal. Chem. 1988, 60, 1203A.

Calibration standards *(continued)*

Element	Source[a]	Purity	Comments[b]
B	SRM 951 (H_3BO_3)	100.00 ± 0.01	E; expose to room humidity (~35%) for 30 min before use.
Al	metal	five 9s	E, M; SRM 1257 Al metal available.
Ga	metal	five 9s	E, M; SRM 994 Ga metal available.
In	metal	five 9s	E, M
Tl	metal	five 9s	E, M; SRM 997 Tl metal available.
C			No recommendation.
Si	metal	six 9s	E, M; SRM 990 SiO_2 available.
Ge	metal	five 9s	E, M
Sn	metal	six 9s	E, M; SRM 741 Sn metal available.
Pb	metal	five 9s	E, M; several SRMs available.
N	NH_4Cl	six 9s	E; can be prepared from HCl + NH_3.
	N_2	>three 9s	E
	HNO_3	six 9s	M; contaminated with NO_x. Purity based on impurities.
P	SRM 194 ($NH_4H_2PO_4$)	three 9s	E
	P_2O_5	five 9s	E, M; difficult to keep dry.
	H_3PO_4	four 9s	E; must titrate 2 hydrogens to be certain of stoichiometry.
As	metal	five 9s	E, M
	SRM 83d (As_2O_3)	99.992 6 ± 0.003 0%	Redox standard. As assay not ensured.
Sb	metal	four 9s	E, M
Bi	metal	five 9s	E, M
O	H_2O	eight 9s	E, M; contains dissolved gases.
	O_2	>four 9s	E
S	element	six 9s	E, M; difficult to dry. Other sources are H_2SO_4, Na_2SO_4, and K_2SO_4. Stoichiometry must be proved (e.g., no SO_3^{2-} present).
Se	metal	five 9s	E, M; SRM 726 Se metal available.
Te	metal	five 9s	E, M
F	NaF	four 9s	E, M; no good directions for drying.
Cl	NaCl	four 9s	E, M; dry for 24 h over $Mg(ClO_4)_2$. Several SRMs (NaCl and KCl) available.
Br	KBr	four 9s	E, M; need to dry and demonstrate stoichiometry.
	Br_2	four 9s	E
I	sublimed I_2	six 9s	E
	KI	three 9s	E, M
	KIO_3	three 9s	Stoichiometry not ensured.