

Appendix A

Electrochemical Reactions and Standard Potentials

	Electrochemical reaction	Standard potential, U^θ
1	$F_2 + 2e^- \rightarrow 2F^-$	2.87
2	$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$	1.685
3	$Cl_2 + 2e^- \rightarrow 2Cl^-$	1.3595
4	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.229
5	$Br_2(aq) + 2e^- \rightarrow 2Br^-$	1.078
6	$Ag^+ + e^- \rightarrow Ag$	0.7991
7	$Hg_2^{2+} + 2e^- \rightarrow 2Hg$	0.789
8	$Cu^+ + e^- \rightarrow Cu$	0.521
9	$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$	0.401
10	$Cu^{2+} + 2e^- \rightarrow Cu$	0.337
11	$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	0.2676
12	$AgCl + e^- \rightarrow Ag + Cl^-$	0.222
13	$Cu^{2+} + e^- \rightarrow Cu^+$	0.153
14	$HgO + H_2O + 2e^- \rightarrow Hg + 2OH^-$	0.098
15	$2H^+ + 2e^- \rightarrow H_2$	0
16	$Pb^{2+} + 2e^- \rightarrow Pb$	-0.126
17	$PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$	-0.356
18	$Fe^{2+} + 2e^- \rightarrow Fe$	-0.440
19	$Cr^{3+} + 3e^- \rightarrow Cr$	-0.74
20	$Zn^{2+} + 2e^- \rightarrow Zn$	-0.763
21	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$	-0.828
22	$Cr^{2+} + 2e^- \rightarrow Cr$	-0.91
23	$Mn^{2+} + 2e^- \rightarrow Mn$	-1.18
24	$Al^{3+} + 3e^- \rightarrow Al$	-1.66
25	$Mg^{2+} + 2e^- \rightarrow Mg$	-2.357
26	$Na^+ + e^- \rightarrow Na$	-2.714
27	$K^+ + e^- \rightarrow K$	-2.936
28	$Li^+ + e^- \rightarrow Li$	-3.045

Standard states, 25 °C, 100 kPa.: (a) gases, pure ideal gas, (b) liquids and solids, pure substance, (c) aqueous, hypothetical 1 molal solution.

Appendix B

Fundamental Constants

Nomenclature	Name	Value	Common units	Expressed in base SI units
R	Universal gas constant	8.3144621	J·mol ⁻¹ ·K ⁻¹	m ² ·kg mol ⁻¹ ·s ⁻² ·K ⁻¹
N_{AV}	Avogadro's number	6.022141 × 10 ²³	mol ⁻¹	mol ⁻¹
k	Boltzmann's constant	1.380649 × 10 ⁻²³	J·K ⁻¹	m ² ·kg·s ⁻² ·K ⁻¹
q	Fundamental unit of charge	1.602177 × 10 ⁻¹⁹	C	A·s
F	Faraday's constant	96,485.34	C/equiv.	A·s/equiv.
ϵ_0	Permittivity of vacuum	8.854188 × 10 ⁻¹²	F·m ⁻¹	m ⁻³ ·kg ⁻¹ ·s ⁴ ·A ²
c	Speed of light	2.99792 × 10 ⁸	m·s ⁻¹	m·s ⁻¹
h	Planck's constant	6.626070 × 10 ⁻³⁴	J·s	m ² ·kg·s ⁻¹

Appendix C

Thermodynamic Data

Table C.1 Standard Enthalpy and Gibbs Energy of Formation from the Elements at 25 °C (298.15 K).

Chemical species	Formula	State	ΔG [kJ·mol ⁻¹]	ΔH [kJ·mol ⁻¹]
Acetic acid	CH ₃ COOH	Liquid	-389.9	-484.3
Acetic acid	CH ₃ COOH	Aqueous	-396.5	-486.1
Aluminum oxide	Al ₂ O ₃	Solid, α	-1582.3	-1675.7
Ammonia	NH ₃	Aqueous	-26.6	-80.3
Ammonia	NH ₃	Gas	-16.4	-45.9
Bromine	Br ₂	Gas	3.1	30.9
Carbon dioxide	CO ₂	Gas	-394.359	-393.509
Carbon monoxide	CO	Gas	-137.2	-110.5
Cobalt(II) oxide	CoO	Solid	-214.2	-237.9
Formaldehyde	CH ₂ O	Gas	-102.5	-108.6
Formic acid	CH ₂ O ₂	Liquid	-361.4	-425.0
Hydrogen bromide	HBr	Gas	-53.4	-36.3
Hydrogen chloride	HCl	Gas	-95.3	-92.3
Hydrogen peroxide	H ₂ O ₂	Liquid	-120.4	-187.8
Hydrogen peroxide	H ₂ O ₂	Gas	-105.6	-136.3
Lead(II) oxide	PbO	Solid	-187.9	-217.3
Lead(IV) oxide	PbO ₂	Solid	-217.3	-277.4
Lead(II, IV) oxide	Pb ₃ O ₄	Solid	-601.7	-718.8
Lead sulfate	PbSO ₄	Solid	-813.302	-919.936
Lithia	Li ₂ O	Solid	-561.2	-597.9
Lithium hydroxide	LiOH	Aqueous	-451.1	-506.9
Lithium iodide	LiI	Solid	-270.3	-270.4
Lithium peroxide	Li ₂ O ₂	Solid	-571.1	-632.6
Mercury(II) chloride	HgCl ₂	Solid	-178.6	-224.3
Mercury(I) chloride	Hg ₂ Cl ₂	Solid	-210.8	-265.2
Methanol	CH ₃ OH	Liquid	-166.6	-239.2
Methane	CH ₄	Gas	-50.5	-74.6
Propane	C ₃ H ₈	Gas	-24.3	-104.7
Silver oxide	Ag ₂ O	Solid	-11.21	-31.1
Silver sulfate	Ag ₂ SO ₄	Solid	-618.4	-715.9
Sodium chloride	NaCl	Solid	-384.1	-411.2
Sodium chloride	NaCl	Aqueous	-393.1	-407.3

(continued)

Table C.1 (Continued)

Chemical species	Formula	State	ΔG [kJ·mol ⁻¹]	ΔH [kJ·mol ⁻¹]
Sodium hydroxide	NaOH	Aqueous	-419.2	-470.1
Sodium oxide	Na ₂ O	Solid	-375.5	-414.2
Sulfur dioxide	SO ₂	Gas	-300.1	-296.8
Sulfuric acid	H ₂ SO ₄	Aqueous	-744.530	-909.3
Water	H ₂ O	Liquid	-237.129	-285.830
Water	H ₂ O	Gas	-228.572	-241.572
Zinc oxide	ZnO	Solid	-320.48	-350.46

Ion	Formula	State	ΔG [kJ·mol ⁻¹]	ΔH [kJ·mol ⁻¹]
Hydrogen	H ⁺	Aqueous	0	0
Aluminum	Al ³⁺	Aqueous	-485.34	-531.37
Ammonium	NH ₄ ⁺	Aqueous	-79.37	-132.51
Calcium	Ca ²⁺	Aqueous	-553.54	-542.83
Copper(I)	Cu ⁺	Aqueous	50.00	71.67
Copper(II)	Cu ²⁺	Aqueous	65.52	64.77
Iron(II)	Fe ²⁺	Aqueous	-84.91	-89.12
Iron(III)	Fe ³⁺	Aqueous	-10.71	-48.53
Lead	Pb ²⁺	Aqueous	-24.39	-1.67
Lithium	Li ⁺	Aqueous	-293.3	-278.49
Magnesium	Mg ²⁺	Aqueous	-454.80	-466.85
Potassium	K ⁺	Aqueous	-283.26	-252.38
Silver	Ag ⁺	Aqueous	77.12	105.57
Sodium	Na ⁺	Aqueous	-261.66	-240.12
Zinc	Zn ²⁺	Aqueous	-147.03	-153.89
Bicarbonate	HCO ₃ ⁻	Aqueous	-586.85	-691.99
Bisulfate	HSO ₄ ⁻	Aqueous	-756.01	-887.34
Bisulfide	HS ⁻	Aqueous	12.6	-17.7
Bisulfite	HSO ₃ ⁻	Aqueous	-527.8	626.2
Bromide	Br ⁻	Aqueous	-103.97	-121.54
Carbonate	CO ₃ ²⁻	Aqueous	-527.89	-677.14
Chloride	Cl ⁻	Aqueous	-131.26	-167.16
Fluoride	F ⁻	Aqueous	-278.82	-332.63
Hydroxyl	OH ⁻	Aqueous	-157.29	-229.99
Iodide	I ⁻	Aqueous	-51.59	-55.19
Nitrate	NO ₃ ⁻	Aqueous	-111.34	-207.36
Perchlorate	ClO ₄ ⁻	Aqueous	-10.8	
Sulfate	SO ₄ ²⁻	Aqueous	-744.62	-909.3
Sulfide	S ²⁻	Aqueous	79.5	30.1
Sulfite	SO ₃ ²⁻	Aqueous	-486.6	-635.5

Standard states: (a) gases, pure ideal gas at 100 kPa, (b) liquids and solids, pure substance at 100 kPa, (c) aqueous, hypothetical 1 molal solution

N. de Nevers (2012) *Physical and Chemical Equilibrium for Chemical Engineers*, John Wiley & Sons, Inc..

D.R. Lide (2000) *CRC Handbook of Chemistry and Physics*, Boca Raton, FL, CRC Press.

M. Pourbaix (1974) *Atlas of Electrochemical Equilibria*, NACE, Houston.

Table C.2 Standard Molar Entropy of Substances at 25 °C (298.15 K) and 100 kPa

Species	Formula	State	Entropy [$\text{J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$]
Hydrogen	H_2	Gas	130.5
Chlorine	Cl_2	Gas	223.1
Oxygen	O_2	Gas	205.03
Iron	Fe	Solid	27.28
Water	H_2O	Gas	188.7
Water	H_2O	Liquid	69.91
Fe(II)	Fe^{2+}	Aqueous	-137.654
Hydrogen	H^+	Aqueous	0
Chloride	Cl^-	Aqueous	56.48
Hydroxyl	OH^-	Aqueous	-10.75

Whereas the Gibbs energy and enthalpy are from an arbitrary datum, entropy values are absolute and therefore nonzero even for elements.

Dean, J.A. (1979) *Lange's Handbook of Chemistry*, 12th ed., McGraw-Hill: New York, NY, pp. 9-4-9-94.