UNIVERSITY OF ESWATINI

DEPARTMENT OF CHEMISTRY

MAIN EXAMINATION 2020/2021

TITLE OF PAPER: SPECIAL ANALYTICAL TECHNIQUES

COURSE NUMBER: CHE 611

TIME ALLOWED: THREE (3) HOURS

INSTRUCTIONS: ANSWER ANY FOUR (4) QUESTIONS

Special Requirements

1. Data sheet.
2. Graph Paper

YOU ARE NOT SUPPOSED TO OPEN THIS PAPER UNTIL PERMISSION TO DO SO HAS BEEN GIVEN BY THE CHIEF INVIGILATOR.

QUESTION 1 [25]

(a) Use energy level diagrams and Planck's Equation to explain the principles of x-ray fluorescence. (3)

(b) Use diagrams to explain how conventional x-ray generators work in XRF. (3)

(c) Describe how soil samples are prepared for XRF analysis. (2)

(d) Explain how:

(i) Geiger counters (3)

(ii) Scintillation counters (3)

work in detecting incoming radiation in wavelength dispersive XRF

(e) Describe how the following interferences affect XRF analysis

(i) X-ray absorption (3)
(ii) X-ray enhancement (3)
(iii) Sample macroscopic effects (3)

(f) Why would analyst opt to use XRF for elemental analysis of soil over ICP optical emission techniques? (2)

QUESTION 2 [25]

(a) (i) Use diagrams to explain the difference between "batch" extraction and "continuous" extraction (5)

(ii) With reference to "matrix effects" in analytical chemistry, explain why solvent extraction may be a necessary step in accurately measuring trace Cu in soils (5)

(b) Use diagrams to explain the

(i) Flow injection Analysis system used to quantify Cu in soils by Atomic Absorption Spectroscopy (FIA-AAS) (7)

(ii) Whatman's Two-Film Theory in the FIA – AAS system (5)

(iii) How the "phase separator" works in FIA – AAS (3)

QUESTION 3 [25]

(a) Explain the fundamental principles of Scanning Electron Microscopy. (3)

(b) Draw the schematic of an SEM, and explain how the electron beam is produced. (3)

(c) Use diagrams to explain the mechanisms of the emission of three signal types during a raster scan in SEM. (3)

(d) Describe how non-conductive samples, such as those containing asbestos fibres, are prepared in SEM. (2)

(e) Explain how it is possible to carry out energy dispersive analysis with SEM. (3)

(f) (i) Explain how incoming photons are detected and processed by solid state detectors in energy dispersive analysis. (3)

(ii) Explain how incoming photons are detected and processed by proportional counters in energy dispersive analysis. (3)

(iii) Explain how incoming photons are detected and processed by PIN diode in energy dispersive analysis. (3)

(g) Why would an anlyst opt to use SEM with EDS when monitoring mining and rehabilitation at asbestos mines? (2)

QUESTION 4 [25]

(a) State the neutron activation equation used to quantify analytes by Instrumental Neutron Activation Analysis, and explain all terms appearing in it. (4)

(b) (i) Draw and fully label the SLOWPOKE II nuclear reactor (6)

(ii) In this reactor, explain the role of the Cd rod (2)

(iii) In this reactor, explain the role of the Be shield (2)

(iv) In this reactor, explain the role of the water pool (2)

(c) (i) Explain how samples are introduced to the reactor in INAA (3)

(ii) Explain how gamma ray photons are detected in INAA (4)

(iii) Why would an analyst prefer to use INAA to determine elements in soil samples over the more conventional flame atomic absorption spectrometer (2)

QUESTION 5 [25]

(a) Describe the Purge-and-Trap GC-MS technique (4)

(b) What is meant by Tandem GC-MS? (3)

(c) Use diagrams to explain how electron ionization is achieved in this technique and equations to explain its mechanism. (4)

(d) Use chemical equation to explain how chemical ionization is achieved in GC-MS. (4)

(e) Explain why an analyst would opt to use GC-MS over the more conventional GC instrument with Thermal Conductivity Detector (TCD), in environmental monitoring. (2)

(f) Describe each of three steps used in Matrix-Assisted Laser Deposition/Ionization (MALDI) used in LC-MS. (4)

(g) Use diagrams to describe the direct electron ionization LC-MS interface (4)

QUESTION 6 [25]

(a) (i) Draw and label the ICP torch (4)

(ii) Write down the Saha Equation, and explain how the ICP is an ideal source of ions for ICP – MS (6)

(b) (i) Draw a schematic diagram of a quadrupole MS instrument, and explain how ions are separated and detected in this instrument (8)

(ii) Draw the interface used to couple the ICP to an MS in ICP – MS (5)

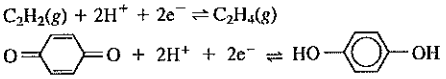
(c) What is meant by "isobaric interferences" in ICP – MS (2)

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. Sillén 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)
$Ca(acetate)^+ + 2e^- \rightleftharpoons Ca(s) + acetate^-$	−2.891	
$CaSO_4(s) + 2e^- \rightleftharpoons Ca(s) + SO_4^{2-}$	−2.936	
$Ca(malonate)(s) + 2e^- \rightleftharpoons Ca(s) + malonate^{2-}$	−3.608	
Carbon		
$C_2H_2(g) + 2H^+ + 2e^- \rightleftharpoons C_2H_4(g)$	0.731	
	0.700	
$CH_3OH + 2H^+ + 2e^- \rightleftharpoons CH_4(g) + H_2O$	0.583	−0.039
$Dehydroascorbic\ acid + 2H^+ + 2e^- \rightleftharpoons ascorbic\ acid + H_2O$	0.390	
$(CN)_2(g) + 2H^+ + 2e^- \rightleftharpoons 2HCN(aq)$	0.373	
$H_2CO + 2H^+ + 2e^- \rightleftharpoons CH_3OH$	0.237	−0.51
$C(s) + 4H^+ + 4e^- \rightleftharpoons CH_4(g)$	0.131 5	−0.209 2
$HCO_2H + 2H^+ + 2e^- \rightleftharpoons H_2CO + H_2O$	−0.029	−0.63
$CO_2(g) + 2H^+ + 2e^- \rightleftharpoons CO(g) + H_2O$	−0.103 8	−0.397 7
$CO_2(g) + 2H^+ + 2e^- \rightleftharpoons HCO_2H$	−0.114	−0.94
$2CO_2(g) + 2H^+ + 2e^- \rightleftharpoons H_2C_2O_4$	−0.432	−1.76
Cerium		
$Ce^{4+} + e^- \rightleftharpoons Ce^{3+}$	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	
$Ce^{3+} + 3e^- \rightleftharpoons Ce(s)$	−2.336	0.280
Cesium		
$Cs^+ + e^- + Hg \rightleftharpoons Cs(in\ Hg)$	−1.950	
$Cs^+ + e^- \rightleftharpoons Cs(s)$	−3.026	−1.172
Chlorine		
$HClO_2 + 2H^+ + 2e^- \rightleftharpoons HOCl + H_2O$	1.674	0.55
$HClO + H^+ + e^- \rightleftharpoons \frac{1}{2}Cl_2(g) + H_2O$	1.630	−0.27
$ClO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}Cl_2(g) + 3H_2O$	1.458	−0.347
$Cl_2(aq) + 2e^- \rightleftharpoons 2Cl^-$	1.396	−0.72
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-$	1.360 4	−1.248
$ClO_4^- + 2H^+ + 2e^- \rightleftharpoons ClO_3^- + H_2O$	1.226	−0.416
$ClO_3^- + 3H^+ + 2e^- \rightleftharpoons HClO_2 + H_2O$	1.157	−0.180
$ClO_3^- + 2H^+ + e^- \rightleftharpoons ClO_2 + H_2O$	1.130	0.074
$ClO_2 + e^- \rightleftharpoons ClO_2^-$	1.068	−1.335
Chromium		
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	1.36	−1.32
$CrO_4^{2-} + 4H_2O + 3e^- \rightleftharpoons Cr(OH)_3\ (s, hydrated) + 5OH^-$	−0.12	−1.62
$Cr^{3+} + e^- \rightleftharpoons Cr^{2+}$	−0.42	1.4
$Cr^{3+} + 3e^- \rightleftharpoons Cr(s)$	−0.74	0.44
$Cr^{2+} + 2e^- \rightleftharpoons Cr(s)$	−0.89	−0.04
Cobalt		
$Co^{3+} + e^- \rightleftharpoons Co^{2+}$	1.92	1.23
	1.817 8 F H_2SO_4	
	1.850 4 F HNO_3	
$Co(NH_3)_5(H_2O)^{3+} + e^- \rightleftharpoons Co(NH_3)_5(H_2O)^{2+}$	0.37 1 F NH_4NO_3	
$Co(NH_3)_6^{3+} + e^- \rightleftharpoons Co(NH_3)_6^{2+}$	0.1	
$CoOH^+ + H^+ + 2e^- \rightleftharpoons Co(s) + H_2O$	0.003	−0.04
$Co^{2+} + 2e^- \rightleftharpoons Co(s)$	−0.282	0.065
$Co(OH)_2(s) + 2e^- \rightleftharpoons Co(s) + 2OH^-$	−0.746	−1.02
Copper		
$Cu^+ + e^- \rightleftharpoons Cu(s)$	0.518	−0.754
$Cu^{2+} + 2e^- \rightleftharpoons Cu(s)$	0.339	0.011
$Cu^{2+} + e^- \rightleftharpoons Cu^+$	0.161	0.776
$CuCl(s) + e^- \rightleftharpoons Cu(s) + Cl^-$	0.137	
$Cu(IO_3)_2(s) + 2e^- \rightleftharpoons Cu(s) + 2IO_3^-$	−0.079	
$Cu(ethylenediamine)_2^{2+} + e^- \rightleftharpoons Cu(s) + 2\ ethylenediamine$	−0.119	
$CuI(s) + e^- \rightleftharpoons Cu(s) + I^-$	−0.185	
$Cu(EDTA)^{2-} + 2e^- \rightleftharpoons Cu(s) + EDTA^{4-}$	−0.216	
$Cu(OH)_2(s) + 2e^- \rightleftharpoons Cu(s) + 2OH^-$	−0.222	
$Cu(CN)_2^- + e^- \rightleftharpoons Cu(s) + 2CN^-$	−0.429	
$CuCN(s) + e^- \rightleftharpoons Cu(s) + CN^-$	−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 0.732 1 F HCl 0.767 1 F $HClO_4$ 0.746 1 F HNO_3 0.68 1 F H_2SO_4	1.175

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		
$NpO_2^+ + 2H^+ + e^- \rightleftharpoons NpO_2^{2+} + H_2O$	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
$\frac{1}{2}N_2(g) + H^+ + e^- \rightleftharpoons HN_3$	−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
$SiO_2(s, \text{quartz}) + 4H^+ + 4e^- \rightleftharpoons Si(s) + 2H_2O$	−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