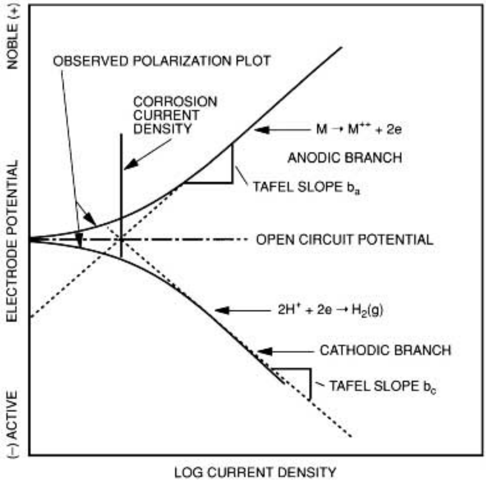
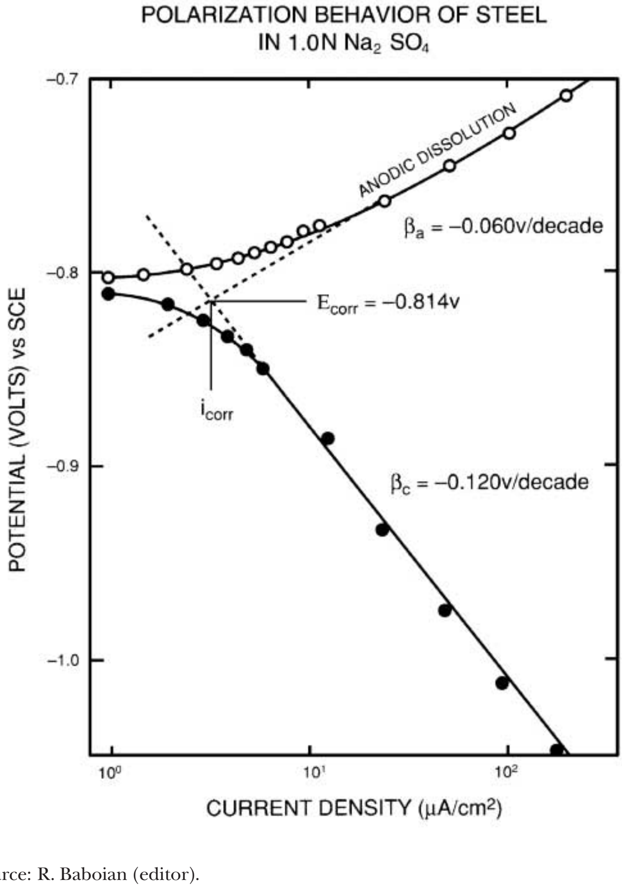
4 Corrosion Testing

HYPOTHETICAL CATHODIC AND ANODIC POLARIZATION DIAGRAM



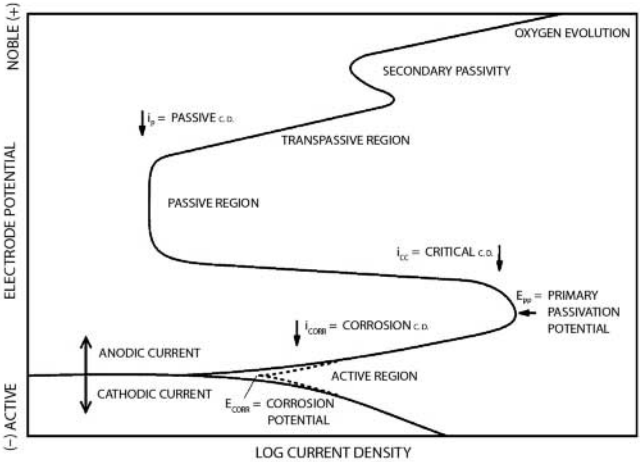
Source: ASTM G3, "Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing" (West Conshohocken, PA, USA: ASTM International, 2000), Fig. 3. Reprinted with permission, copyright ASTM.

TYPICAL CATHODIC AND ANODIC POLARIZATION DIAGRAM



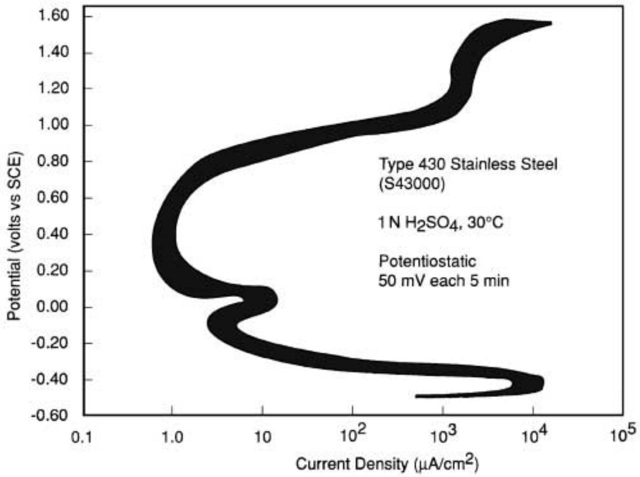
Source: R. Baboian (editor).

HYPOTHETICAL CATHODIC AND ANODIC POLARIZATION PLOTS FOR A PASSIVE ANODE



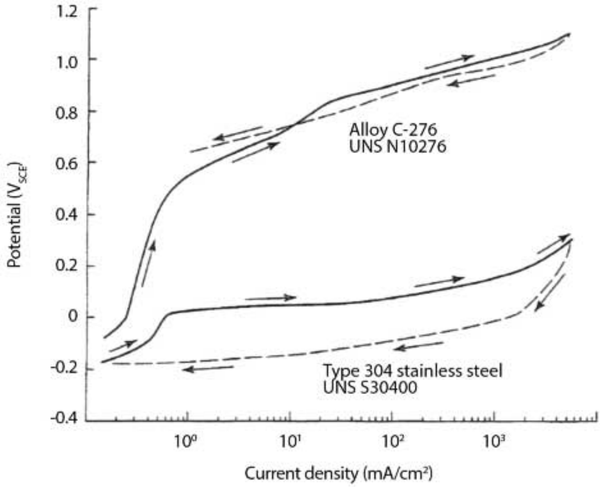
Source: ASTM G3, "Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing" (West Conshohocken, PA, USA: ASTM International, 2000), Fig. 4. Reprinted with permission, copyright ASTM.

TYPICAL STANDARD POTENTIOSTATIC ANODIC POLARIZATION PLOT



Source: ASTM G5, "Standard Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements" (West Conshohocken, PA, USA: ASTM International, 2000), Fig. 4. Reprinted with permission, copyright ASTM.

CYCLIC POTENTIODYNAMIC POLARIZATION CURVES IN CHLORIDE SOLUTION



Source: ASTM G61, "Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron-, Nickel-, or Cobalt-Based Alloys" (West Conshohocken, PA, USA: ASTM International, 2014), Fig. 2. Reprinted with permission, copyright ASTM.

DATA FOR TAFEL EQUATION CALCULATIONS

$$\eta = \beta \log \frac{i}{i_0}$$

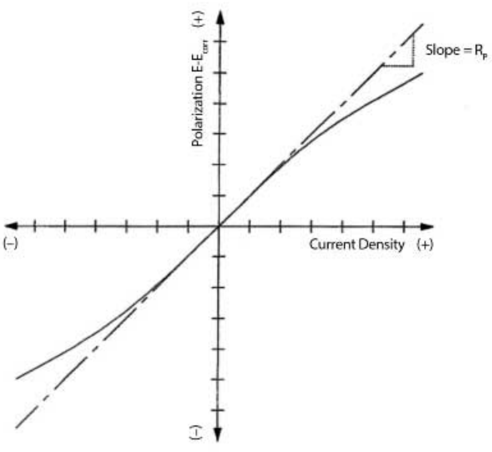
Metal	Temperature ˚C	Solution	β volts	i_o A/m²	η [1 mA/cm² (V)]*
		Hydrogen Overvoltage			
Pt	20	1N HCl	0.03	10	0.00
(smooth)	25	0.1N NaOH	0.11	0.68	0.13
Pd	20	0.6N HCl	0.03	2	0.02
Mo	20	1N HCl	0.04	10−2	0.12
Au	20	1N HCl	0.05	10−2	0.15
Ta	20	1N HCl	0.08	10−1	0.16
W	20	5N HCl	0.11	10−1	0.22
Ag	20	0.1N HCl	0.09	5×10^{-3}	0.30
Ni	20	0.1N HCl	0.10	8×10^{-3}	0.31
	20	0.12N NaOH	0.10	4×10^{-3}	0.34
Bi	20	1N HCl	0.10	10−3	0.40
Nb	20	1N HCl	0.10	10−3	0.40
Fe	16	1N HCl	0.15	10−2	0.45
	25	4% NaCl pH 1-4	0.10	10−3	0.40 (Stern)
Cu	20	0.1N HCl	0.12	2×10^{-3}	0.44
	20	0.15N NaOH	0.12	1×10^{-2}	0.36
Sb	20	2N H_2SO_4	0.10	10−5	0.60
Al	20	2N H_2SO_4	0.10	10−6	0.70
Be	20	1N HCl	0.12	10−5	0.72
Sn	20	1N HCl	0.15	10−4	0.75
Cd	16	1N HCl	0.20	10−3	0.80
Zn	20	1N H_2SO_4	0.12	1.6×10^{-7}	0.94
Hg	20	0.1N HCl	0.12	7×10^{-9}	1.10
	20	0.1N H_2SO_4	0.12	2×10^{-9}	1.16
	20	0.1N NaOH	0.10	3×10^{-11}	1.15
Pb	20	0.01-8N HCl	0.12	2×10^{-9}	1.16

Metal	Temperature °C	Solution	β volts	i_o A/m²	η [1 mA/cm² (V)]*
		Oxygen Overvoltage			
Pt	20	0.1N H_2SO_4	0.10	9×10^{-8}	0.81
(smooth)	20	0.1N NaOH	0.05	4×10^{-9}	0.47
Au	20	0.1N NaOH	0.05	5×10^{-9}	0.47
		Metal Overvoltage (deposition)			
Zn	25	1M $ZnSO_4$	0.12	0.2	0.20 (Bockris)
Cu	25	1M $CuSO_4$	0.12	0.2	0.20 (Bockris)
Fe	25	1M $FeSO_4$	0.12	10−4	0.60 (Bockris)
Ni	25	1M $NiSO_4$	0.12	2×10^{-5}	0.68 (Bockris)

*1 mA/cm² = 10 A/m²

Source: H.H. Uhlig, *Corrosion and Corrosion Control*, 3rd ed. (Hoboken, New Jersey, USA: John Wiley & Sons, 1985), p. 44. Reprinted with permission, copyright John Wiley & Sons, Inc.

HYPOTHETICAL POLARIZATION RESISTANCE PLOT



Source: ASTM G3, “Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing” (West Conshohocken, PA, USA: ASTM International, 2014), Fig. 2. Reprinted with permission, copyright ASTM.

POLARIZATION RESISTANCE METHOD FOR DETERMINING CORROSION RATES

Defining the polarization resistance R_p as

$$R_p = \left(\frac{\partial\phi}{\partial I}\right)_{\phi_{corr}}$$

and combining the constants as

$$B = \frac{b_a\, b_c}{2.303(b_a + b_c)}$$

the corrosion current I_{corr} can be calculated as

$$I_{corr} = \frac{b_a\, b_c}{2.303(b_a + b_c)} \left(\frac{\partial I}{\partial\phi}\right)_{\phi_{corr}}$$

$$= \frac{B}{R_p}$$

The dimension of R_p as determined from a potential-current plot is ohms (Ω). In order to obtain a value of R_p, which is independent of the electrode surface and which can be converted into corrosion rates, polarization resistance values should be reported in $\Omega{\cdot}cm^2$ (e.g., $mV/mA/cm^2$).

See following page for typical values for constant B.

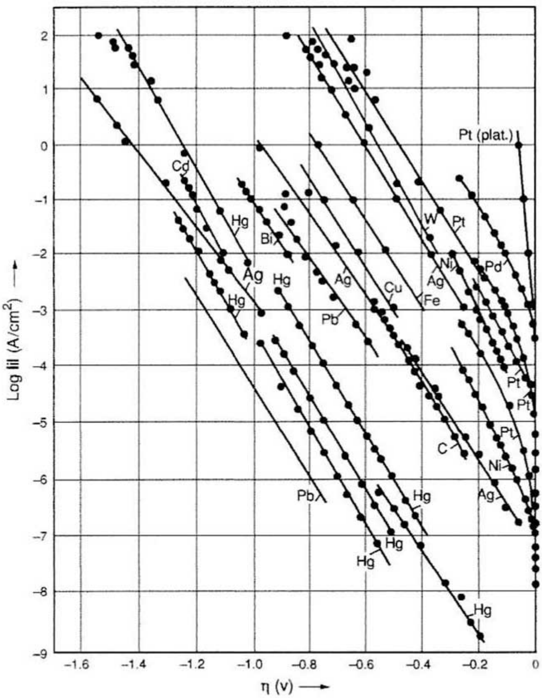
Source: F. Mansfield, *Electrochemical Techniques for Corrosion* (Houston, TX, USA: NACE International, 1977), pp. 18–26.

VALUES OF THE CONSTANT B FOR THE POLARIZATION RESISTANCE METHOD

Corroding System	b_a, mV	b_c, mV	B, mV
Theoretical	30	30	6.5
(Values of B calculated from arbitrary	30	60	9
b_a and b_c values using formula on	30	120	10
previous page; b_a and b_c values	30	180	11
can be interchanged.)	30	∞	13
	60	60	13
	60	90	16
	60	120	17
	60	180	20
	60	∞	26
	90	90	20
	90	120	22
	90	180	26
	90	∞	39
	120	120	26
	120	∞	52
	180	180	39
	180	∞	78
Iron, 4% NaCl, pH 1.5	–	–	17
Iron, 0.5N H_2SO_4, 30 C	–	–	17
Iron, 1N H_2SO_4	–	–	10–20
Iron, 1N HCl	–	–	18–23
Iron, 0.02M citric acid, pH 2.6. 35 C	–	–	12
Carbon steel, seawater	57	∞	25
Carbon steel, 1N Na_2SO_4, H_2, pH 6.3, 30 C	–	–	19
304L SS, 1N H_2SO_4, O_2	inf.	50	22
304 SS, lithiated water, 288 C	85	160	24
304 SS, 3% NaCl, 90 C	inf.	50	22
430 SS, 1N H_2SO_4, H_2, 30 C	–	–	20
600 alloy, lithiated water, 288 C	82	160	24
Al 1199, 1N NaCl, pH 2, 30 C	–	–	44
Aluminum, seawater	45	600	18
Zircaloy 2, lithiated water, 288 C	inf.	186	81
OFHC Copper, 1N NaCl, H_2, pH 6.2, 30 C	–	–	26

Source: Adapted from a collection of literature values compiled by F. Mansfeld, *Electrochemical Techniques for Corrosion* (Houston, TX, USA: NACE International, 1977), pp. 18, 26.

HYDROGEN OVERVOLTAGE ON VARIOUS ELECTRODE MATERIALS



Source: C.A. Hampel.

STANDARD REFERENCE POTENTIALS AND CONVERSION TABLE

REFERENCE POTENTIALS

Electrode	Potential (V) @ 25 °C E'^{b}	E''^{c}	Thermal Temperature Coefficient[a] (mV/°C)
$(Pt)/H_2$ ($\alpha=1$)/H + ($\alpha=1$) (SHE)	0.000	···	+0.87
Ag/AgCl/1M KCl	+0.235	···	+0.25
Ag/AgCl/0.6M Cl^- (seawater)	+0.25	···	···
Ag/AgCl/0.1M Cl^-	+0.288	···	+0.22
Hg/Hg_2Cl_2/sat KCl (SCE)	+0.241	+0.244	+0.22
Hg/Hg_2Cl_2/1M KCl	+0.280	+0.283	+0.59
Hg/Hg_2Cl_2/0.1M KCl	+0.334	+0.336	+0.79
$Cu/CuSO_4$ sat	+0.30	···	+0.90
$Hg/Hg_2SO_4/H_2SO_4$	+0.616	···	+0.09

a. To convert from thermal to isothermal temperature coefficients, subtract 0.87 mV/°C. Thus the isothermal temperature coefficient for Ag/AgCl/1M KCl is −0.62 mV/°C.
b. E' is the standard potential for the half cell corrected for the concentration of the ions.
c. E'' also includes the liquid junction potentials for a saturated KCl salt bridge.

CONVERSION FACTORS[d]

From (E')	To SHE Scale	To SCE Scale (E')
H_2/H^+	...	−0.241
Ag/AgCl/1M KCl	+0.235	−0.006
Ag/AgCl/0.6M Cl^- (seawater)	+0.25	+0.009
Ag/AgCl/0.1M Cl^-	+0.288	+0.047
Hg/Hg_2Cl_2/sat KCl (SCE)	+0.241	...
Hg/Hg_2Cl_2/1M KCl	+0.280	+0.039
Hg/Hg_2Cl_2/0.1M KCl	+0.334	+0.093
$Cu/CuSO_4$ sat	+0.30	+0.06
$Hg/Hg_2SO_4/H_2SO_4$	+0.616	...

d. To convert from one scale to another, add the value indicated.

Example:

An electrode potential of +1.000V versus SCE would be (1.000 + 0.241) = +1.241V versus SHE. An electrode potential of −1.000V versus SCE would give (−1.000 + 0.241) =

−0.759V versus SHE.

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ELECTROCHEMICAL SERIES

REDUCTION REACTIONS HAVING E° VALUES MORE POSITIVE THAN THAT OF THE STANDARD HYDROGEN ELECTRODE

Reaction	E°, V
$2\ H^+ + 2\ e \rightleftharpoons H_2$	0.00000
$CuI_2^- + e \rightleftharpoons Cu + 2\ I^-$	0.00
$Ge^{4+} + 2\ e \rightleftharpoons Ge^{2+}$	0.00
$NO_3^- + H_2O + 2\ e \rightleftharpoons NO_2^- + 2\ HO^-$	0.01
$Tl_2O_3 + 3\ H_2O + 4\ e \rightleftharpoons 2\ Tl^+ + 6\ OH^-$	0.02
$SeO_4^{2-} + H_2O + 2\ e \rightleftharpoons SeO_3^{2-} + 2\ OH^-$	0.05
$UO_2^{2+} + e \rightleftharpoons UO_2^+$	0.062
$Pd(OH)_2 + 2\ e \rightleftharpoons Pd + 2\ OH^-$	0.07
$AgBr + e \rightleftharpoons Ag + Br^-$	0.07133
$S_4O_6^{2-} + 2\ e \rightleftharpoons 2\ S_2O_3^{2-}$	0.08
$AgSCN + e \rightleftharpoons Ag + SCN^-$	0.8951
$N_2 + 2\ H_2O + 6\ H^+ + 6\ e \rightleftharpoons 2\ NH_4OH$	0.092
$HgO + H_2O + 2\ e \rightleftharpoons Hg + 2\ OH^-$	0.0977
$Ir_2O_3 + 3\ H_2O + 6\ e \rightleftharpoons 2\ Ir + 6\ OH^-$	0.098
$2\ NO + 2\ e \rightleftharpoons N_2O_2^{2-}$	0.10
$[Co(NH_3)_6]^{3+} + e \rightleftharpoons [Co(NH_3)_6]^{2+}$	0.108
$Hg_2O + H_2O + 2\ e \rightleftharpoons 2\ Hg + 2\ OH^-$	0.123
$Ge^{4+} + 4\ e \rightleftharpoons Ge$	0.124
$Hg_2Br_2 + 2\ e \rightleftharpoons 2\ Hg + 2\ Br^-$	0.13923
$Pt(OH)_2 + 2\ e \rightleftharpoons Pt + 2\ OH^-$	0.14
$S + 2\ H^+ + 2\ e \rightleftharpoons H_2S(aq)$	0.142
$Np^{4+} + e \rightleftharpoons Np^{3+}$	0.147
$Ag_4[Fe(CN)_6] + 4\ e \rightleftharpoons 4\ Ag + [Fe(CN)_6]^{4-}$	0.1478
$Mn(OH)_3 + e \rightleftharpoons Mn(OH)_2 + OH^-$	0.15
$2\ NO_2^- + 3\ H_2O + 4\ e \rightleftharpoons N_2O + 6\ OH^-$	0.15
$Sn^{4+} + 2\ e \rightleftharpoons Sn^{2+}$	0.151
$Sb_2O_3 + 6\ H^+ + 6\ e \rightleftharpoons 2\ Sb + 3\ H_2O$	0.152
$Cu^{2+} + e \rightleftharpoons Cu^+$	0.153
$BiOCl + 2\ H^+ + 3\ e \rightleftharpoons Bi + Cl^- + H_2O$	0.1583
$Bi(Cl)_4^- + 3\ e \rightleftharpoons Bi + 4\ Cl^-$	0.16
$Co(OH)_3 + e \rightleftharpoons Co(OH)_2 + OH^-$	0.17
$SO_4^{2-} + 4\ H^+ + 2\ e \rightleftharpoons H_2SO_3 + H_2O$	0.172
$SbO^+ + 2\ H^+ + 3\ e \rightleftharpoons Sb + 2\ H_2O$	0.212
$AgCl + e \rightleftharpoons Ag + Cl^-$	0.22233
$As^2O_3 + 6\ H^+ + 6\ e \rightleftharpoons 2\ As + 3\ H_2O$	0.234
Calomel electrode, saturated NaCl (SSCE)	0.2360
$Ge^{2+} + 2\ e \rightleftharpoons Ge$	0.24
Calomel electrode, saturated KCl	0.2412
$PbO_2 + H_2O + 2\ e \rightleftharpoons PbO + 2\ OH^-$	0.247
$HAsO_2 + 3\ H^- + 3_c \rightleftharpoons As + 2\ H_2O$	0.248
$Ru^{3+} + e \rightleftharpoons Ru^{2+}$	0.2487
$ReO_2 + 4\ H^+ + 4\ e \rightleftharpoons Re + 2\ H_2O$	0.2513
$IO_3^- + 3\ H_2O + 6\ e \rightleftharpoons I^- + OH^-$	0.26
$Hg_2Cl_2 + 2\ e \rightleftharpoons 2\ Hg + 2\ Cl^-$	0.26808
Calomel electrode, molal KCl	0.2800
Calomel electrode, 1 mol/1 KCl (NCE)	0.2801
$Re^{3+} + 3\ e \rightleftharpoons Re$	0.300
$BiO^+ + 2\ H^+ + 3\ e \rightleftharpoons Bi + H_2O$	0.320
$UO_2^{2+} + 4\ H^+ + 2\ e \rightleftharpoons U^{4+} + 2\ H_2O$	0.327
$ClO_3^- + H_2O + 2\ e \rightleftharpoons ClO_2^- + 2\ OH^-$	0.33
$2\ HCNO + 2\ H^+ + 2\ e \rightleftharpoons (CN)_2 + 2\ H_2O$	0.330
Calomel electrode, 0.1 mol/l KCl	0.3337
$VO^{2+} + 2\ H^+ + e \rightleftharpoons V^{3+} + H_2O$	0.337
$Cu^{2+} + 2\ e \rightleftharpoons Cu$	0.3419
$Ag_2O + H_2O + 2\ e \rightleftharpoons 2\ Ag + 2\ OH^-$	0.342
$Cu^{2+} + 2\ e \rightleftharpoons Cu(Hg)$	0.345

Reaction	E°, V	Reaction	E°, V
$AgIO_3 + e \rightleftharpoons Ag + IO_3^-$	0.354	$MnO_4^- + 2\,H_2O + 3\,e \rightleftharpoons MnO_2 + 4\,OH^-$	0.595
$[Fe(CN)_6]^{3-} + e \rightleftharpoons [Fe(CN)_6]^{4-}$	0.358	$Rh^{2+} + 2\,e \rightleftharpoons Rh$	0.600
$ClO_4^- + H_2O + 2\,e \rightleftharpoons ClO_3^- + 2\,OH^-$	0.36	$Rh^+ + e \rightleftharpoons Rh$	0.600
$Ag_2SeO_3 + 2\,e \rightleftharpoons 2\,Ag + SeO_3^{2-}$	0.3629	$MnO_4^{2-} + 2\,H_2O + 2\,e \rightleftharpoons MnO_2 + 4\,OH^-$	0.60
$ReO_4^- + 8\,H^+ + 7\,e \rightleftharpoons Re + 4\,H_2O$	0.368	$2\,AgO + H_2O + 2\,e \rightleftharpoons Ag_2O + 2\,OH^-$	0.607
$(CN)_2 + 2\,H^+ + 2\,e \rightleftharpoons 2\,HCN$	0.373	$BrO_3^- + 3\,H_2O + 6\,e \rightleftharpoons Br^- + 6\,OH^-$	0.61
$[Ferricinium]^+ + e \rightleftharpoons$ ferrocene	0.400	$UO_2^+ + 4\,H^+ + e \rightleftharpoons U^{4+} + 2\,H_2O$	0.612
$Tc^{2+} + 2\,e \rightleftharpoons Tc$	0.400	$Hg_2SO_4 + 2\,e \rightleftharpoons 2\,Hg + SO_4^{2-}$	0.6125
$O_2 + 2\,H_2O + 4\,e \rightleftharpoons 4\,OH^-$	0.401	$ClO_3^- + 3\,H_2O + 6\,e \rightleftharpoons Cl^- + 6\,OH^-$	0.62
$AgOCN + e \rightleftharpoons Ag + OCN^-$	0.41	$Hg_2HPO_4 + 2\,e \rightleftharpoons 2\,Hg + HPO_4^{2-}$	0.6359
$[RhCl_6]^{3-} + 3\,e \rightleftharpoons Rh + 6\,Cl^-$	0.431	$Ag(ac) + e \rightleftharpoons Ag + (ac)^-$	0.643
$Ag_2CrO_4 + 2\,e \rightleftharpoons 2\,Ag + CrO_4^{2-}$	0.4470	Sb_2O_5 (valentinite) $+ 4\,H^+ + 4\,e \rightleftharpoons Sb_2O_3 + 2\,H_2O$	0.649
$H_2SO_3 + 4\,H^+ + 4\,e \rightleftharpoons S + 3\,H_2O$	0.449	$Ag_2SO_4 + 2\,e \rightleftharpoons 2\,Ag + SO_4^{2-}$	0.654
$Ru^{2+} + 2\,e \rightleftharpoons Ru$	0.455	$ClO_2^- + H_2O + 2\,e \rightleftharpoons ClO^- + 2\,OH^-$	0.66
$Ag_2MoO_4 + 2\,e \rightleftharpoons 2\,Ag + MoO_4^{2-}$	0.4573	Sb_2O_5 (senarmontite) $+ 4\,H^+ + 4\,e \rightleftharpoons Sb_2O_3 + 2\,H_2O$	0.671
$Ag_2C_2O_4 + 2\,e \rightleftharpoons 2\,Ag + C_2O_4^{2-}$	0.4647	$[PtCl_6]^{2-} + 2\,e \rightleftharpoons [PtCl_4]^{2-} + 2\,Cl^-$	0.68
$Ag_2WO_4 + 2\,e \rightleftharpoons 2\,Ag + WO_4^{2-}$	0.4660	$O_2 + 2\,H^+ + 2\,e \rightleftharpoons H_2O_2$	0.695
$Ag_2CO_3 + 2\,e \rightleftharpoons 2\,Ag + CO_3^{2-}$	0.47	p-benzoquinone $+ 2\,H^+ + 2\,e \rightleftharpoons$ hydroquinone	0.6992
$TeO_4^- + 8\,H^+ + 7\,e \rightleftharpoons Te + 4\,H_2O$	0.472	$H_3IO_6 + 2\,e \rightleftharpoons IO_3^- + 3\,OH^-$	0.7
$IO^- + H_2O + 2\,e \rightleftharpoons I^- + 2\,OH^-$	0.485	$Ag_2O_3 + H_2O + 2\,e \rightleftharpoons 2\,AgO + 2\,OH^-$	0.739
$ReO_4^- + 4\,H^+ + 3\,e \rightleftharpoons ReO_2 + 2\,H_2O$	0.510	$[PtCl_4]^{2-} + 2\,e \rightleftharpoons Pt + 4\,Cl^-$	0.755
$Hg_2(ac)_2 + 2\,e \rightleftharpoons 2\,Hg + 2\,(ac)^-$	0.51163	$Rh^{3+} + 3\,e \rightleftharpoons Rh$	0.758
$Cu^+ + e \rightleftharpoons Cu$	0.521	$ClO_2^- + 2\,H_2O + 4\,e \rightleftharpoons Cl^- + 4\,OH^-$	0.76
$I_2 + 2\,e \rightleftharpoons 2\,I^-$	0.5355	$2\,NO + H_2O + 2\,e \rightleftharpoons N_2O + 2\,OH^-$	0.76
$I^3 + 2\,e \rightleftharpoons 3\,I^-$	0.536	$BrO^- + H_2O + 2\,e \rightleftharpoons Br^- + 2\,OH^-$	0.761
$AgBrO_3 + e \rightleftharpoons Ag + BrO_3^-$	0.546	$ReO_4^- + 2\,H^+ + e \rightleftharpoons ReO_3 + H_2O$	0.768
$MnO_4^- + e \rightleftharpoons MnO_4^{2-}$	0.558	$(CNS)_2 + 2\,e \rightleftharpoons 2\,CNS^-$	0.77
$H_3AsO_4 + 2\,H^+ + 2\,e^- \rightleftharpoons HAsO_2 + 2\,H_2O$	0.560	$[IrCl_6]^{3-} + 3e \rightleftharpoons Ir + 6\,Cl^-$	0.77
$IO_3^- + 2\,H_2O + 4\,e \rightleftharpoons IO^- + 4\,OH^-$	0.56	$Fe^{3+} + e \rightleftharpoons Fe^{2+}$	0.771
$S_2O_6^{2-} + 4\,H^+ + 2\,e \rightleftharpoons 2\,H_2SO_3$	0.564	$Ag(F) + e \rightleftharpoons Ag + F^-$	0.779
$AgNO_2 + e \rightleftharpoons Ag + NO_2^-$	0.564	$TcO_4^- + 4\,H^+ + 3\,e \rightleftharpoons TcO_2 + 2\,H_2O$	0.782
$Te^{4+} + 4\,e \rightleftharpoons Te$	0.568	$Hg_2^{2+} + 2\,e \rightleftharpoons 2\,Hg$	0.7973
$Sb_2O_5 + 6\,H^+ + 4\,e \rightleftharpoons 2\,SbO^+ + 3\,H_2O$	0.581	$Ag^+ + e \rightleftharpoons Ag$	0.7996
$RuO_4^- + e \rightleftharpoons RuO_4^{2-}$	0.59	$2\,NO_3^- + 4\,H^+ + 2\,e \rightleftharpoons N_2O_4 + 2\,H_2O$	0.803
$[PdCl_4]^{2-} + 2\,e \rightleftharpoons Pd + 4\,Cl^-$	0.591	$ClO^- + H_2O + 2\,e \rightleftharpoons Cl^- + 2\,OH^-$	0.841
$TeO_2 + 4\,H^+ + 4\,e \rightleftharpoons Te + 2\,H_2O$	0.593	$OsO_4 + 8\,H^+ + 8\,e \rightleftharpoons Os + 4\,H_2O$	0.85

ELECTROCHEMICAL SERIES

Reaction	E°, V
$Hg^{2+} + 2\,e \rightleftharpoons Hg$	0.851
$AuBr_4^- + 3\,e \rightleftharpoons Au + 4\,Br^-$	0.854
SiO_2 (quartz) $+ 4\,H^+ + 4\,e \rightleftharpoons Si + 2\,H_2O$	0.857
$2\,HNO_2 + 4\,H^+ + 4\,e \rightleftharpoons H_2N_2O_2 + H_2O$	0.86
$[IrCl_6]^{2-} + e \rightleftharpoons [IrCl_6]^{3-}$	0.8665
$N_2O_4 + 2\,e \rightleftharpoons 2\,NO_2^-$	0.867
$HO_2^- + H_2O + 2\,e \rightleftharpoons 3\,OH^-$	0.878
$2\,Hg^{2+} + 2\,e \rightleftharpoons Hg_2^{2+}$	0.920
$NO_3^- + 3\,H^+ + 2\,e \rightleftharpoons HNO_2 + H_2O$	0.934
$Pd^{2+} + 2\,e \rightleftharpoons Pd$	0.951
ClO_2 (aq) $+ e \rightleftharpoons ClO_2^-$	0.954
$NO_3^- + 4\,H^+ + 3\,e \rightleftharpoons NO + 2\,H_2O$	0.957
$AuBr_2^- + e \rightleftharpoons Au + 2\,Br^-$	0.959
$HNO_2 + H^+ + e \rightleftharpoons NO + H_2O$	0.983
$HIO + H^+ + 2\,e \rightleftharpoons I^- + H_2O$	0.987
$VO_2^+ + 2\,H^+ + e \rightleftharpoons VO^{2+} + H_2O$	0.991
$RuO_4 + e \rightleftharpoons RuO_4^-$	1.00
$V(OH)_4^+ + 2\,H^+ + e \rightleftharpoons VO^{2+} + 3\,H_2O$	1.00
$AuCl_4^- + 3\,e \rightleftharpoons Au + 4\,Cl^-$	1.002
$Pu^{4+} + e \rightleftharpoons Pu^{3+}$	1.006
$H_6TeO_6 + 2\,H^+ + 2\,e \rightleftharpoons TeO_2 + 4\,H_2O$	1.02
$N_2O_4 + 4\,H^+ + 4\,e \rightleftharpoons 2\,NO + 2\,H_2O$	1.035
$[Fe(phen)_3]^{3+} + e \rightleftharpoons [Fe(phen)_3]^{2+}$ (1 mol/l H_2SO_4)	1.06
$PuO_2(OH)_2 + H^+ + e \rightleftharpoons PuO_2OH + H_2O$	1.062
$N_2O_4 + 2\,H^+ + 2\,e \rightleftharpoons 2\,HNO_2$	1.065
$Br_2(l) + 2\,e \rightleftharpoons 2\,Br^-$	1.066
$IO_3^- + 6\,H^+ + 6\,e \rightleftharpoons I^- + 3\,H_2O$	1.085
$Br_2(aq) + 2\,e \rightleftharpoons 2\,Br^-$	1.0873
$Pu^{5+} + e \rightleftharpoons Pu^{4+}$	1.099
$Cu^{2+} + 2\,CN^- + e \rightleftharpoons [Cu(CN)2]^-$ $Pt^{2+} + 2\,e \rightleftharpoons Pt$	1.118
$RuO_2 + 4\,H^+ + 2\,e \rightleftharpoons Ru^{2+} + 2\,H_2O$	1.120
$[Fe(phenanthroline)_3]^{3+} + e \rightleftharpoons [Fe(phen)_3]^{2+}$	1.147
$SeO_4^{2-} + 4\,H^+ + 2\,e \rightleftharpoons H_2SeO_3 + H_2O$	1.151
$ClO_3^- + 2\,H^+ + e \rightleftharpoons ClO_2 + H_2O$	1.152
$Ir^{3+} + 3\,e \rightleftharpoons Ir$	1.156
$ClO_4^- + 2\,H^+ + 2\,e \rightleftharpoons ClO_3^- + H_2O$	1.189
$2\,IO_3^- + 12\,H^+ + 10\,e \rightleftharpoons I_2\ 6\,H_2O$	1.195
$ClO_3^- + 3\,H^+ + 2\,e \rightleftharpoons HClO_2 + H_2O$	1.214
$MnO_2 + 4\,H^+ + 2\,e \rightleftharpoons Mn^{2+} + 2\,H_2O$	1.224
$O_2 + 4\,H^+ + 4\,e \rightleftharpoons 2\,H_2O$	1.229
$Cr_2O_7^{2-} + 14\,H^+ + 6\,e \rightleftharpoons 2\,Cr^{3-} + 7\,H_2O$	1.232
$O_3 + H_2O + 2\,e \rightleftharpoons O_2 + 2\,OH^-$	1.24
$Tl^{3+} + 2\,e \rightleftharpoons Tl^+$	1.252
$N_2H_5^+ + 3\,H^+ + 2\,e \rightleftharpoons 2\,NH_4^+$	1.275
$ClO_2 + H^+ + e \rightleftharpoons HClO_2$	1.227
$[PdCl_6]^{2-} + 2\,e \rightleftharpoons [PdCl_4]^{2-} + 2\,Cl^-$	1.288
$2\,HNO_2 + 4\,H^+ + 4\,e \rightleftharpoons N_2O + 3\,H_2O$	1.297
$PuO_2(OH)_2 + 2\,H^+ + 2\,e \rightleftharpoons Pu(OH)_4$	1.325
$HBrO + H^+ + 2\,e \rightleftharpoons Br^- + H_2O$	1.331
$HCrO_4^- + 7\,H^+ + 3\,e \rightleftharpoons Cr^{3+} + 4\,H_2O$	1.350
$Cl_2(g) + 2\,e \rightleftharpoons Cl^-$	1.35827
$ClO_4^- + 8\,H^+ + 8\,e \rightleftharpoons Cl^- + 4\,H_2O$	1.389
$ClO_4^- + 8\,H^+ + 7\,e \rightleftharpoons 1/2\,Cl_2 + 4\,H_2O$	1.39
$Au^{3+} + 2\,e \rightleftharpoons Au^+$	1.401
$2\,NH_3OH^+ + H^+ + 2\,e \rightleftharpoons N_2H_5^+ + 2\,H_2O$	1.42
$BrO_3^- + 6\,H^+ + 6\,e \rightleftharpoons Br^- + 3\,H_2O$	1.423
$2\,HIO + 2\,H^+ + 2\,e \rightleftharpoons I_2 + 2\,H_2O$	1.439
$Au(OH)_3 + 3\,H^+ + 3\,e \rightleftharpoons Au^- + 3\,H_2O$	1.45
$3IO_3^- + 6\,H^+ + 6\,e \rightleftharpoons Cl^- + 3\,H_2O$	1.451
$PbO_2 + 4\,H^- + 2\,e \rightleftharpoons Pb^{2+} + 2\,H_2O$	1.455
$ClO_3^- + 6\,H^+ + 5\,e \rightleftharpoons 1/2\,Cl_2 + 3\,H_2O$	1.47
$BrO_3^- + 6\,H^+ + 5\,e \rightleftharpoons 1/2\,Br_2 + 3\,H_2O$	1.482
$HClO + H^+ + 2\,e \rightleftharpoons Cl^- + H_2O$	1.482
$HO_2 + H^+ + e \rightleftharpoons H_2O_2$	1.495
$Au^{3+} + 3\,e \rightleftharpoons Au$	1.498
$MnO_4^- + 8\,H^+ + 5\,e \rightleftharpoons Mn^{2+} + 4\,H_2O$	1.507
$Mn^{3+} + e \rightleftharpoons Mn^{2+}$	1.5415
$HClO_2 + 3\,H^+ + 4\,e \rightleftharpoons Cl^- + 2\,H_2O$	1.570
$HBrO + H^+ + e \rightleftharpoons 1/2\,Br_2(aq) + H_2O$	1.574
$2\,NO + 2\,H^+ + 2\,e \rightleftharpoons N_2O + H_2O$	1.591
$Bi_2O_4 + 4\,H^+ + 2\,e \rightleftharpoons 2\,BiO^+ + 2\,H_2O$	1.593
$HBrO + H^+ + e \rightleftharpoons 1/2\,Br_2(l) + H_2O$	1.596

Reaction	E°, V	Reaction	E°, V
$H_5IO_6 + H^+ + 2e \rightleftharpoons IO_3^- + 3H_2O$	1.601	$Co^{3+} + e \rightleftharpoons Co^{2+}$ (2 mol/l H_2SO_4)	1.83
$Ce^{4+} + e \rightleftharpoons Ce^{3+}$	1.61	$Ag^{2+} + e \rightleftharpoons Ag^+$	1.980
$HClO + H^+ + e \rightleftharpoons 1/2\,Cl_2 + H_2O$	1.611	$S_2O_8^{2-} + 2e \rightleftharpoons 2SO_4^{2-}$	2.010
$HClO_2 + 3H^+ + 3e \rightleftharpoons 1/2\,Cl_2 + 2H_2O$	1.628	$OH + e \rightleftharpoons OH^-$	2.02
$HClO_2 + 2H^+ + 2e \rightleftharpoons HClO + H_2O$	1.645	$O_3 + 2H^+ + 2e \rightleftharpoons O_2 + H_2O$	2.076
$NiO_2 + 4H^+ + 2e \rightleftharpoons Ni^{2+} + 2H_2O$	1.678	$S_2O_8^{2-} + 2H^+ + 2e \rightleftharpoons 2HSO_4^{2-}$	2.123
$MnO_4^- + 4H^+ + 3e \rightleftharpoons MnO_2 + 2H_2O$	1.679	$F_2O + 2H^+ + 4e \rightleftharpoons H_2O + 2F^-$	2.153
$PbO_2 + SO_4^{2-} + 4H^+ + 2e \rightleftharpoons PbSO_4 + 2H_2O$	1.6913	$FeO_4^{2-} + 8H^+ + 3e \rightleftharpoons Fe^{3+} + 4H_2O$	2.20
$Au^+ + e \rightleftharpoons Au$	1.692	$O(g) + 2H^+ + 2e \rightleftharpoons H_2O$	2.421
$CeOH^{3+} + H^+ + e \rightleftharpoons Ce^{3+} + H_2O$	1.715	$H_2N_2O_2 + 2H^+ + 2e \rightleftharpoons N_2 + 2H_2O$	2.65
$N_2O + 2H^+ + 2e \rightleftharpoons N_2 + H_2O$	1.766	$F_2 + 2e \rightleftharpoons 2F^-$	2.866
$H_2O_2 + 2H^+ + 2e \rightleftharpoons 2H_2O$	1.776	$F_2 + 2H^+ + 2e \rightleftharpoons 2HF$	3.053

REDUCTION REACTIONS HAVING E° VALUES MORE NEGATIVE THAN THAT OF THE STANDARD HYDROGEN ELECTRODE

Reaction	E°, V	Reaction	E°, V
$2H^+ + 2e \rightleftharpoons H_2$	−0.00000	$WO_2 + 4H^+ + 4e \rightleftharpoons W + 2H_2O$	−0.119
$AgCN + e \rightleftharpoons Ag + CN^-$	−0.017	$Pb^{2+} + 2e \rightleftharpoons Pb(Hg)$	−0.1205
$2WO_3 + 2H^+ + 2e \rightleftharpoons W_2O_5 + H_2O$	−0.029	$Pb^{2+} + 2e \rightleftharpoons Pb$	−0.1262
$W_2O_5 + 2H^+ + 2e \rightleftharpoons 2WO_2 + H_2O$	−0.031	$CrO_4^{2-} + 4H_2O + 3e \rightleftharpoons Cr(OH)_3 + 5OH^-$	−0.13
$D^+ + e \rightleftharpoons 1/2\,D_2$	−0.0034	$Sn^{2-} + 2e \rightleftharpoons Sn$	−0.1375
$Ag_2S + 2H^+ + 2e \rightleftharpoons Ag + H_2S$	−0.0366	$In^+ + e \rightleftharpoons In$	−0.14
$Fe^{3+} + 3e \rightleftharpoons Fe$	−0.037	$O_2 + 2H_2O + 2e \rightleftharpoons H_2O_2 + 2OH^-$	−0.146
$Hg_2I_2 + 2e \rightleftharpoons 2Hg + 2I^-$	−0.0405	$AgI + e \rightleftharpoons Ag + I^-$	−0.15224
$2D^+ + 2e \rightleftharpoons D_2$	−0.044	$2NO_2^- + 2H_2O + 4e \rightleftharpoons N_2O_2^{2-} + 4OH^-$	−0.18
$Tl(OH)_3 + 2e \rightleftharpoons TlOH + 2OH^-$	−0.05	$H_2GeO_3 + 4H^+ + 4e \rightleftharpoons Ge + 3H_2O$	−0.182
$TiOH^{3+} + H^+ + e \rightleftharpoons Ti^{3+} + H_2O$	−0.055	$Co_2 + 2H^+ + 2e \rightleftharpoons HCOOH$	−0.199
$2H_2SO_3 + H^+ + 2e \rightleftharpoons HS_2O_4^- + 2H_2O$	−0.056	$Mo^{3+} + 3e \rightleftharpoons Mo$	−0.200
$P(white) + 3H^+ + 3e \rightleftharpoons PH_3(g)$	−0.063	$2SO_2^{2-} + 4H^+ + 2e \rightleftharpoons S_2O_6^{2-} + H_2O$	−0.22
$O_2^- + H_2O + 2e \rightleftharpoons HO_2^- + OH^-$	−0.076	$Cu(OH)_2 + 2e \rightleftharpoons Cu + 2OH^-$	−0.222
$2Cu(OH)_2 + 2e \rightleftharpoons Cu_2O + 2OH^- + H_2O$	−0.080	$CdSO_4 + 2e \rightleftharpoons Cd + SO_4^{2-}$	−0.246
$WO_3 + 6H^+ + 6e \rightleftharpoons W + 3H_2O$	−0.090	$V(OH)_4^- + 4H^+ + 5e \rightleftharpoons V + 4H_2O$	−0.254
$P(red) + 3H^+ + 3e \rightleftharpoons PH_3(g)$	−0.111	$V^{3+} + e \rightleftharpoons V^{2+}$	−0.255
$GeO_2 + 2H^+ + 2e \rightleftharpoons GeO + H_2O$	−0.118	$Ni^{2+} + 2e \rightleftharpoons Ni$	−0.257

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Reaction	E°, V
$PbCl_2 + 2\,e \rightleftharpoons Pb + 2\,Cl^-$	−0.2675
$H_3PO_4 + 2\,H^+ + 2\,e \rightleftharpoons H_3PO_3 + H_2O$	−0.276
$Co^{2+} + 2\,e \rightleftharpoons Co$	−0.28
$PbBr_2 + 2\,e \rightleftharpoons Pb + 2\,Br^-$	−0.284
$Tl^+ + e \rightleftharpoons Tl(Hg)$	−0.3338
$Tl^+ + e \rightleftharpoons Tl$	−0.336
$In^{3+} + 3\,e \rightleftharpoons In$	−0.3382
$TlOH + e \rightleftharpoons Tl + OH^-$	−0.34
$PbF_2 + 2\,e \rightleftharpoons Pb + 2\,F^-$	−0.3444
$PbSO_4 + 2\,e \rightleftharpoons Pb(Hg) + SO_4^{2-}$	−0.3505
$Cd^{2+} + 2\,e \rightleftharpoons Cd(Hg)$	−0.3521
$PbSO_4 + 2\,e \rightleftharpoons Pb + SO_4^{2-}$	−0.3588
$Cu_2O + H_2O + 2\,e \rightleftharpoons 2\,Cu + 2\,OH^-$	−0.360
$Eu^{3+} + e \rightleftharpoons Eu^{2+}$	−0.36
$PbI_2 + 2\,e \rightleftharpoons Pb + 2\,I^-$	−0.365
$Se_3^{2-} + 3\,H_2O + 4\,e \rightleftharpoons Se + 6\,OH^-$	−0.366
$Ti^{3+} + e \rightleftharpoons Ti^{2+}$	−0.368
$Se + 2\,H^+ + 2\,e \rightleftharpoons H_2Se(aq)$	−0.399
$In^{2+} + e \rightleftharpoons In^+$	−0.40
$Cd^{2+} + 2\,e \rightleftharpoons Cd$	−0.4030
$Cr^3 + e \rightleftharpoons Cr^{2+}$	−0.407
$2\,S + 2\,e \rightleftharpoons S_2^{2-}$	−0.42836
$Tl_2SO_4 + 2\,e \rightleftharpoons Tl + SO_4^{2-}$	−0.4360
$In^{3+} + 2\,e \rightleftharpoons In^+$	−0.443
$Fe^{2+} + 2\,e \rightleftharpoons Fe$	−0.447
$H_3PO_3 + 3\,H^+ + 3\,e \rightleftharpoons P + 3\,H_2O$	−0.454
$Bi_2O_3 + 3\,H_2O + 6\,e \rightleftharpoons 2\,Bi + 6\,OH^-$	−0.46
$NO_2^- + H_2O + e \rightleftharpoons NO + 2\,OH$	−0.46
$PbHPO_4 + 2\,e \rightleftharpoons Pb + HPO_4^{2-}$	−0.465
$S + 2\,e \rightleftharpoons S^{2-}$	−0.47627
$S + H_2O + 2\,e \rightleftharpoons HS^- + OH^-$	−0.478
$NiO_2 + 2\,H_2O + 2\,e \rightleftharpoons Ni(OH)_2 + 2\,OH^-$	−0.490
$In^{3+} + e \rightleftharpoons In^{2+}$	−0.49
$H_3PO_3 + 2\,H^+ + 2\,e \rightleftharpoons H_3PO_2 + H_2O$	−0.499
$TiO_2 + 4\,H^+ + 2\,e \rightleftharpoons Ti^{2+} + 2\,H_2O$	−0.502
$H_3PO_2 + H^+ + e \rightleftharpoons P + 2\,H_2O$	−0.508
$Sb + 3\,H^+ + 3\,e \rightleftharpoons SbH_3$	−0.510
$HPbO_2^- + H_2O + 2\,e \rightleftharpoons Pb + 3\,OH^-$	−0.537
$TlCl + e \rightleftharpoons Tl + Cl^-$	−0.5568
$Ga^{3+} + 3\,e \rightleftharpoons Ga$	−0.560
$Fe(OH)_3 + e \rightleftharpoons Fe(OH)_2 + OH^-$	−0.56
$TeO_3^{2-} + 3\,H_2O + 4\,e \rightleftharpoons Te + 6\,OH^-$	−0.57
$2\,SO_3^{2-} + 3\,H_2O + 4\,e \rightleftharpoons S_2O_3^{2-} + 6\,OH^-$	−0.571
$PbO + H_2O + 2\,e \rightleftharpoons Pb + 2\,OH^-$	−0.580
$ReO_2^- + 4\,H_2O + 7\,e \rightleftharpoons Re + 8\,OH^-$	−0.584
$SbO_3^- + H_2O + 2\,e \rightleftharpoons SbO_2^- + 2\,OH^-$	−0.59
$U^{4+} + e \rightleftharpoons U^{3+}$	+0.607
$As + 3\,H^+ + 3\,e \rightleftharpoons AsH_3$	−0.608
$Nb_2O_5 + 10\,H^+ + 10\,e \rightleftharpoons 2\,Nb + 5\,H_2O$	−0.644
$TlBr + e \rightleftharpoons Tl + Br^-$	−0.658
$SbO_2^- + 2\,H_2O + 3\,e \rightleftharpoons Sb + 4\,OH^-$	−0.66
$AsO_2^- + 2\,H_2O + 3\,e \rightleftharpoons As + 4\,OH^-$	−0.68
$Ag_2S + 2\,e \rightleftharpoons 2\,Ag + S^{2-}$	−0.691
$AsO_4^{3-} + 2\,H_2O + 2\,e \rightleftharpoons AsO_2^- + 4\,OH^-$	−0.71
$Ni(OH)_2 + 2\,e \rightleftharpoons Ni + 2\,OH^-$	−0.72
$Co(OH)_2 + 2\,e \rightleftharpoons Co + 2\,OH^-$	−0.73
$H_2SeO_3 + 4\,H^+ + 4\,e \rightleftharpoons Se + 3\,H_2O$	−0.74
$Cr^{3+} + 3\,e \rightleftharpoons Cr$	−0.744
$Ta_2O_5 + 10\,H^+ + 10\,e \rightleftharpoons 2\,Ta + 5\,H_2O$	−0.750
$TlI + e \rightleftharpoons Tl + I^-$	−0.752
$Zn^{2+} + 2\,e \rightleftharpoons Zn$	−0.7618
$Zn^{2+} + 2\,e \rightleftharpoons Zn(Hg)$	−0.7628
$Te + 2\,H^+ + 2\,e \rightleftharpoons H_2Te$	−0.793
$ZnSO_4 \cdot 7H_2O + 2\,e \rightleftharpoons Zn(Hg) + SO_4^{2-}$ (Sat'd $ZnSO_4$)	−0.7993
$Cd(OH)_2 + 2\,e \rightleftharpoons Cd(Hg) + 2\,OH^-$	−0.809
$2\,H_2O + 2\,e \rightleftharpoons H_2 + 2\,OH^-$	−0.8277
$2\,NO_3^- + 2\,H_2O + 2\,e \rightleftharpoons N_2O_4 + 4\,OH^-$	−0.85
$H_3BO_3 + 3\,H^+ + 3\,e \rightleftharpoons B + 3\,H_2O$	−0.8698
$P + 3\,H_2O + 3\,e \rightleftharpoons PH_3(g) + 3\,OH^-$	−0.87
$HSnO_2^- + H_2O + 2\,e \rightleftharpoons Sn + 3\,OH^-$	−0.909
$Cr^{2+} + 2\,e \rightleftharpoons Cr$	−0.913
$Se + 2\,e \rightleftharpoons Se^{2-}$	−0.924

Reaction	E°, V	Reaction	E°, V
$SO_4^{2-} + H_2O + 2\,e \rightleftharpoons SO_3^{2-} + 2\,OH^-$	−0.93	$Th^{4+} + 4\,e \rightleftharpoons Th$	−1.899
$Sn(OH)_6^{2-} + 2\,e \rightleftharpoons HSNO_2^- + 3\,OH^- + H_2O$	−0.93	$Pu^{3+} + 3\,e \rightleftharpoons Pu$	−2.031
$NpO_2 + H_2O + H^+ + e \rightleftharpoons Np(OH)_3$	−0.962	$AlF_6^{3-} + 3\,e \rightleftharpoons Al + 6\,F^-$	−2.069
$PO_4^{3-} + 2\,H_2O + 2\,e \rightleftharpoons HPO_3^{2-} + 3\,OH^-$	−1.05	$Sc^{3+} + 3\,e \rightleftharpoons Sc$	−2.077
$Nb^{3+} + 3\,e \rightleftharpoons Nb$	−1.099	$H_2 + 2\,e \rightleftharpoons 2\,H^-$	−2.23
$2\,SO_3^{2-} + 2\,H_2O + 2\,e \rightleftharpoons S_2O_4^{2-} + 4\,OH^-$	−1.12	$H_2AlO_3^- + H_2O + 3\,e \rightleftharpoons Al + 4\,OH^-$	−2.33
$Te + 2\,e \rightleftharpoons Te^{2-}$	−1.143	$ZrO(OH)_2 + H_2O + 4\,e \rightleftharpoons Zr + 4\,OH^-$	−2.36
$V^{2+} + 2\,e \rightleftharpoons V$	−1.175	$Mg^{2+} + 2\,e \rightleftharpoons Mg$	−2.372
$Mn^{2+} + 2\,e \rightleftharpoons Mn$	−1.185	$Y^{3+} + 3\,e \rightleftharpoons Y$	−2.372
$CrO_2^- + 2\,H_2O + 3\,e \rightleftharpoons Cr + 4\,OH^-$	−1.2	$Eu^{3+} + 3\,e \rightleftharpoons Eu$	−2.407
$ZnO_2^- + 2\,H_2O + 2\,e \rightleftharpoons Zn + 4\,OH^-$	−1.215	$Nd^{3+} + 3\,e \rightleftharpoons Nd$	−2.431
$H_2GaO_3^- + H_2O + 3\,e \rightleftharpoons Ga + 4\,OH^-$	−1.219	$Th(OH)_4 + 4\,e \rightleftharpoons Th + 4\,OH^-$	− 2.48
$H_2BO_3^- + 5\,H_2O + 8\,e \rightleftharpoons BH_4^- + 8\,OH^-$	−1.24	$Ce^{3+} + 3\,e \rightleftharpoons Ce$	−2.483
$SiF_6^{2-} + 4\,e \rightleftharpoons Si + 6\,F^-$	−1.24	$HfO(OH)_2 + H_2O + 4\,e \rightleftharpoons Hf + 4\,OH^-$	−2.50
$Ce^{3+} + 3\,e \rightleftharpoons Ce(Hg)$	−1.4373	$La^{3+} + 3\,e \rightleftharpoons La$	−2.522
$UO_2^{2+} + 4\,H^+ + 6\,e \rightleftharpoons U + 2\,H_2O$	−1.444	$Be_2O_3^{2-} + 3\,H_2O + 4\,e \rightleftharpoons 2\,Be + 6\,OH^-$	−2.63
$Cr(OH)_3 + 3\,e \rightleftharpoons Cr + 3\,OH^-$	−1.48	$Mg(OH)_2 + 2\,e \rightleftharpoons Mg + 2\,OH^-$	−2.690
$HfO_2 + 4\,H^+ + 4\,e \rightleftharpoons Hf + 2\,H_2O$	−1.505	$Mg^+ + e \rightleftharpoons Mg$	−2.70
$ZrO_2 + 4\,H^+ + 4\,e \rightleftharpoons Zr + 2\,H_2O$	−1.553	$Na^+ + e \rightleftharpoons Na$	−2.71
$Mn(OH)_2 + 2\,e \rightleftharpoons Mn + 2\,OH^-$	−1.56	$Ca^{2+} + 2\,e \rightleftharpoons Ca$	−2.868
$Ba^{2+} + 2\,e \rightleftharpoons Ba(Hg)$	−1.570	$Sr(OH)_2 + 2\,e \rightleftharpoons Sr + 2\,OH^-$	−2.88
$Ti^{2+} + 2\,e \rightleftharpoons Ti$	−1.630	$Sr^{2+} + 2\,e \rightleftharpoons Sr$	−2.89
$HPO_3^{2-} + 2\,H_2O + 2\,e \rightleftharpoons H_2PO_2^- + OH^-$	−1.65	$La(OH)_3 + 3\,e \rightleftharpoons La + 3\,OH^-$	−2.90
$Al^{3+} + 3\,e \rightleftharpoons Al$	−1.662	$Ba^{2+} + 2\,e \rightleftharpoons Ba$	−2.912
$SiO_3^{2-} + H_2O + 4\,e \rightleftharpoons Si + 6\,OH^-$	−1.697	$Cs^+ + e \rightleftharpoons Cs$	−2.92
$HPO_3^{2-} + 2\,H_2O + 3\,e \rightleftharpoons P + 5\,OH^-$	−1.71	$K^+ + e \rightleftharpoons K$	−2.931
$HfO^{2+} + 2\,H^+ + 4\,e \rightleftharpoons Hf + H_2O$	−1.724	$Rb^- + e \rightleftharpoons Rb$	−2.98
$ThO_2 + 4\,H^- + 4\,e \rightleftharpoons Th + 2\,H_2O$	−1.789	$Ba(OH)_2 + 2\,e \rightleftharpoons Ba + 2\,OH^-$	−2.99
$H_2BO_3^- + H_2O + 3\,e \rightleftharpoons B + 4\,OH^-$	−1.79	$Ca(OH)_2 + 2\,e \rightleftharpoons Ca + 2\,OH^-$	−3.02
$Sr^{2+} + 2\,e \rightleftharpoons Sr(Hg)$	−1.793	$Li^+ + e \rightleftharpoons Li$	−3.0401
$U^{3+} + 3\,e \rightleftharpoons U$	−1.798	$3\,N_2 + 2\,H^+ + 2\,e \rightleftharpoons 2\,NH_3$	−3.09
$H_2PO_2^- + e \rightleftharpoons P + 2\,OH^-$	−1.82	$Eu^{2+} + 2\,e \rightleftharpoons Eu$	−3.395
$Be^{2+} + 2\,e \rightleftharpoons Be$	−1.847	$Ca^+ + e \rightleftharpoons Ca$	−3.80
$Np^{3+} + 3\,e \rightleftharpoons Np$	−1.856	$Sr^+ + e \rightleftharpoons Sr$	−4.10

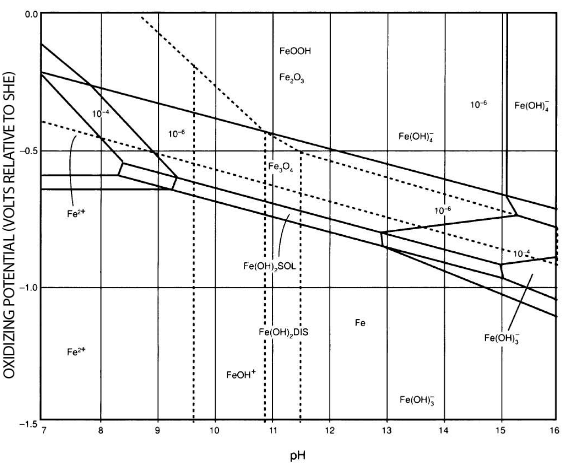
EMF SERIES FOR METALS

Electrode Reaction	Standard Potential at 25 °C (77 °F), Volts versus SHE
$Au^{3+} + 3e^- \rightarrow Au$	1.50
$Pd^{2+} + 2e^- \rightarrow Pd$	0.987
$Hg^{2+} + 2e^- \rightarrow Hg$	0.854
$Ag^+ + e^- \rightarrow Ag$	0.800
$Hg_2 + -2 + 2e \rightarrow 2Hg.$	0.789
$Cu^+ + e^- \rightarrow Cu$	0.521
$Cu^{2+} + 2e^- \rightarrow Cu$	0.337
$2 H^+ + 2e^- \rightarrow H_2$	(Reference) 0.000
$Pb^{2+} + 2e^- \rightarrow Pb$	−0.126
$Sn2 + 2e^- \rightarrow Sn$	−0.136
$Ni^{2+} + 2e^- \rightarrow Ni$	−0.250
$Co^{2+} + 2e^- \rightarrow Ni$	−0.277
$Tl^+ + e^- \rightarrow Tl$	−0.336
$In^{3+} + 3e^- \rightarrow In$	−0.342
$Cd^{2+} + 2e^- \rightarrow Cd$	−0.403
$Fe^{2+} + 2e^- \rightarrow Fe$	−0.440
$Ga^{3+} + 3e^- \rightarrow Ga$	−0.53
$Cr^{3+} + 3e^- \rightarrow Cr$	−0.74
$Cr^{2+} + 2e^- \rightarrow Cr$	−0.91
$Zn^{2+} + 2e^- \rightarrow Zn$	−0.763
$Mn^{2+} + 2e^- \rightarrow Mn$	−1.18
$Zr^{4+} + 4e^- \rightarrow Zr$	−1.53
$Ti^{2+} + 2e^- \rightarrow Ti$	−1.63
$Al^{3+} + 3e^- \rightarrow Al$	−1.66
$Hf^{4+} + 4e^- \rightarrow Hf$	−1.70
$U^{3+} + 3e^- \rightarrow U$	−1.80
$Be^{2+} + 2e^- \rightarrow Be$	−1.85
$Mg^{2+} + 2e^- \rightarrow Mg$	−2.37

Electrode Reaction	Standard Potential at 25 ˚C (77 ˚F), Volts versus SHE
$Na^+ + e^- \rightarrow Na$	−2.71
$Ca^{2+} + 2e^- \rightarrow Ca$	−2.87
$K^+ + e^- \rightarrow K$	−2.93
$Li^+ + e^- \rightarrow Li$	−3.05

Source: L.J. Korb, *Metals Handbook*, 9th ed., Vol. 13 (Materials Park, OH, USA: ASM International, 1987), p. 20. Reprinted with permission from ASM International.

TYPICAL POTENTIAL-pH (POURBAIX) DIAGRAM IRON IN WATER AT 25˚C



IONIC SPECIES ARE AT ACTIVITIES OF 10^{-4} AND 10^{-6}

Source: M. Pourbaix, *Atlas of Electrochemical Equlibria in Aqueous Solutions* (Houston, TX, USA: NACE International, 1974), p. 313.

PARTIAL LISTING OF ALLOY AND SPECIES CONDUCIVE TO ENVIRONMENTAL CRACKING

Alloys	Stress Corrosion Cracking	Hydrogen Cracking	Liquid Metal Cracking
Group 1:			
Magnesium	Aqueous Cl^- plus oxidants	Na (125 C) Zn (450 C)	No information
Aluminum	Aqueous Cl^- plus oxidants	No information	Hg (30 C), Ga(50 C), In (180 C), Na (125 C), Sn (260 C), Zn (450 C)
Group 2:			
Carbon steels	NaOH, NH_3, NO_3^-, CN^-, HCO_3, $CO/CO_2/H_2O$	Hardened or cold-worked	Cu, Zn (450˚), In (180˚), Li (210˚), Cd (350˚)
High Strength Steels	See Carbon steels above	Yes	Cu, Cd
18% Maraging Steel	No information	No information	50:50 Pb-Bi
Group 3:			
Martensitic S.S.	NaOH, NaCl	Hardened	No information
Ferritic S.S.	NaOH, Marine tropical atmospheres	Cathodic protection > -850 mv to $Cu:CuSO_4$	No information
Austenitic S.S.	Cl^-, Cl^-/H_2S, NaOH, $H_2S_2O_6$, supercritical water plus O_2	Severely cold-worked	Zn, Cd, Al, Cu
Precipitation– Hardening S.S.	Cl-, NaOH	Hardened	Zn, Cd, Al (Cu?)
Superaustenitics	NaOH	Severely cold-worked	Zn, Cd, Al (Cu?)
Group 4:			
Lead, Tin, Zinc	No information	No information	No information
Group 5:			
Copper alloys	NH_3, HNO_3, SO_2 Steam vs Si Bronze	Impressed current C.P.	Hg
Group 6:			
Nickel N02200	HF plus O_2, H_2SiF_6	No information	S, Hg, Bi, Li, Pb, Sn
Monel N04400	HF plus O_2, H_2SiF_6	Galvanic couples in alk. sulfides	S, Hg, Bi, Li, Pb, Sn
Alloy B, N10001	Azo dyes, Supercritical water plus O_2	No information	Al, Cd, Li
Group 7:			
Inconel N06600	NaOH (300˚C), $AlCl_3$, Supercritical water plus O_2	Cold-worked plus H_2S/Cl^-	S, Zn, Cd, Al
Alloy C N10002	$FeCl_3$, Supercritical water plus O_2	Cold-worked plus H_2S/Cl^- with galvanic couple	S, Zn, Cd, Al
Alloy C276 N10276	Supercritical water plus O_2	Cold-worked plus H_2S/Cl^- with galvanic couple	S, Zn, Cd, Al
Group 8:			
Vitallium (Cobalt)	Magnesium chloride, NaOH	Cold-worked	No information
Group 9:			
Titanium	NaCl (>275˚C), 10% HCl, Chlorinated or fluorinated solvents, methanol	Does Not Apply	Hg (30˚C), Cd (350 C), Ag
Zirconium	$FeCl_3$, I_2, HCl + Fe^{+++} (250 ppm)	Does Not Apply	No information
Group 10:			
Silver, gold, platinum	No identified species	No information	No information

Source: C.P. Dillon, ed., *Forms of Corrosion-Recognition and Prevention*, Vol. 1 (Houston, TX, USA: NACE International, 1982), p. 59.

STANDARD ENVIRONMENTS FOR ENVIRONMENTAL CRACKING TESTS

Standard	Environment	Temperature °C	Materials
NACE TM0177	5.0% NaCl + 0.5% Acetic acid, saturated with H_2S (1 atm.)	21–27	All metals
ASTM G35	Polythionic acid solution	22–25	Stainless steels Related nickel-chromium-iron alloys
ASTM G36	45% $MgCl_2$ (boiling)	154–156	Stainless steels Related alloys
ASTM G37	Mattsson's Solution. pH 7.2 ($CuSO_4 + (NH_4)_2SO_4 + NH_4OH$)	18–24	Copper-zinc base alloys
ASTM G41	NaCl or other salts or synthetic seawater	230–450	All metals
ASTM G44, G47	3.5% NaCl (alt. immersion)	26–28	Aluminum alloys Ferrous alloys
ASTM G103	6% NaCl	Boiling	Al-Zn-Mg alloys
ASTM G123	25% NaCl, pH 1.5 with phosphoric acid	Boiling	Stainless steels
ISO 9591	3.5% NaCl, (alt.immersion)	25	Aluminum alloys
ISO 9591	2.0% NaCl 0.5% Na_2CrO_4 pH = 3.0	25	Aluminum alloys
ISO 15324	0.1 M NaCl Dripped on 300 °C specimen	20–26	Stainless steels Nickel based alloys

SPECIMEN TYPES USED IN ENVIRONMENTAL CRACKING TESTS

			Product Form					Used to Determine				
Loading System	**Specimen Type**	**Standard**	**Sheet**	**Bar**	**Plate**	**Tube**	**Wire**	**T_f**	**σth**	**K_{Iscc}**	**da/dt**	**I_{Icc}**
Constant Load	Bent Beam	–		X	X			X	X			
	Notched beam	–		X	X			X	X	X		
	Direct tension	ASTM G49		X	X	X		X	X			
Constant Strain	U-bend	ASTM G30	X					X				
	Cup	–	X			X						
	C-ring	ASTM G38		X	X	X		X	X			
	Bent beam	ASTM G39	X	X	X	X		X	X			
	Direct tension	ASTM G49		X	X	X		X	X			
	Tuning fork	–		X	X			X				
	Weld bead	–			X			X				
	Rough ground	–	X					X				
	Hairpin	–	X				X	X				
Slow Strain Rate	Round tensile	–		X	X	X			X			X
	Tube	–				X						X
Sustained-LoadingCrack-Growth	DCB	–			X	X				X	X	

T_f time to failure. σ_{th} threshold stress. K_{Iscc} threshold stress intensity. da/dt crack growth rate. I_{ICC} index of susceptibility.
Sources: ISO Standard 7,539, “Corrosion of metals and alloys – Stress corrosion testing” Parts 2 through 5 (Geneva, Switzerland: ISO, 1995), Part 6 (Geneva, Switzerland: ISO, 2003), Part 7 (Geneva, Switzerland: ISO, 2005), Part 8 (Geneva, Switzerland: ISO, 2000) and NACE Standard TM0177, “Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments (Houston, TX, USA: NACE International, 2005).

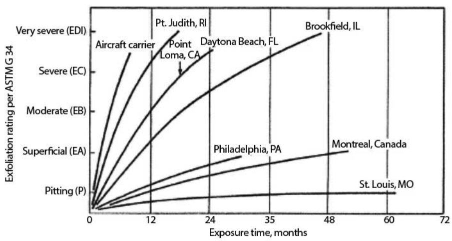
INTERGRANULAR CORROSION TESTS

ASTM standard practices in A 262 for detecting susceptibility to intergranular corrosion in austenitic stainless steels.

Designation	Test	Temperature	Testing Time	Applicability	Evaluation Model
Practice A	Oxalic Acid Etch Screening Test	ambient	1.5 min	Chromium carbide sensitization only	Microscopic Examination; Classification of each structure
B	Ferric Sulfate-50%	boiling	120 h	Chromium carbide	Weight-loss/corrosion rate
C	65% Nitric Acid	boiling	240 h	Chromium carbide and sigma phase	Weight-loss/corrosion rate
D	10% Nitric-3% Hydrofluoric Acids (This test is being removed from A 262)	70˚C	4 h	Chromium carbide in 316, 136L, 317, 317L	Ratio of corrosion; Rates of "unknown" over that of a solution annealed specimen
E	6% Copper Sulfate 16% Sulfuric Acid with metallic copper	boiling	24 h	Chromium carbide	Examination for fissures after bending
F	Copper Sulfate 50% Sulfuric Acid with metallic copper	boiling	120 h	Chromium carbide in cast 316 and 316L	Weight-loss/corrosion rate
ASTM standard practices in A 763 for detecting susceptibility to intergranular corrosion in ferritic stainless steels.					
Practice W	Oxalic Acid Etch	ambient	1.5 min	stabilized (Ti, Cb) grades only	Classification of etch structures
X	Ferric Sulfate-50% Sulfuric Acid	boiling	24 to 120 h	17 to 29% Cr	Weight-loss 17 to 26% Cr, microscopic examination, 29% Cr
Y	Copper Sulfate 50% Sulfuric Acid	boiling	96 to 120 h	25-29% Cr	Weight-loss 26% Cr, microscopic examination, 29% Cr
Z	Copper Sulfate 16% Sulfuric Acid with metallic copper	boiling	24 h	17-18% Cr	Check for fissures in bend test

Source: R. Baboian, ed., Manual 20, 2nd ed., *Corrosion Tests and Standards: Application and Interpretation* (West Conshohocken, PA, USA: ASTM International, 2005), p. 252.

EXFOLIATION CORROSION OF ALUMINUM ALLOY



Influence of the environment on AA 2124 with an E.D. rating in the Standard Exco Test, ASTM G34.

Source: R. Baboian, ed., Manual 20, 2nd ed., *Corrosion Tests and Standards: Application and Interpretation* (West Conshohocken, PA, USA: ASTM International, 2005), p. 267.

DEALLOYING NOMENCLATURE

Selective Attack Called	Removes	From Alloy System
Dealuminization	Aluminum	Copper-aluminum
Decobaltification	Cobalt	Stellite (Co-Cr-W-C)
Decuprification	Copper	Copper-silver copper-gold
Demanganization	Manganese	Copper-manganese
Denickelification	Nickel	Copper-nickel
Desiliconification	Silicon	Silicon-copper
(no name yet)	Silver	Silver-gold
(no name)	Tin	Lead-tin (solders)
Graphite corrosion	Iron	Iron-Carbon (gray cast iron)

Source: P. Roberge, *Corrosion Basics*, 2nd ed. (Houston, TX, USA: NACE International, 2006), p. 389.

DEALLOY MECHANISMS

Mechanism	Temp.	Features	Evidence	Alloys
Volume Diffusion	HT	Bulk diffusion accounts for all atoms ionized at interface	Intermediate composition phases found by X-ray diffraction	Au-Ag, Au-Cu, Cu-Ni, Co-Pt
Vacancy Diffusion	RT HT	di- and trivacancies create pipeline diffusion	Mathematical model and X-ray diffraction data	Au-Cu, Co-Pt, others
Surface Diffusion	RT	High Energy Sites (Kinks and Jogs) allow dissolution of less noble metal	Mathematical simulation	Au-Cu, Au-Ag, Cu-Zn, others
Oxide Formation	RT	Noble metal oxide is metastable phase oxide rearranges to noble metal islands	Electron diffraction pattern shows extra spots	Au-Ag only
Percolation	RT	Inner-connectedness of lattice allows less noble metal to be removed	Mathematical simulation of structure	Au-Ag, Fe-Cr, Ni-Co, others
Dissolution and Reprecipitation	RT	Dissolution of both components, reprecipitation of more noble component, as islands	Solution chemistry crystals of pure metals electron diffraction shows rings	Au-Ag, Cu-Zn, Fe-Ni, others

Source: R. Baboian, ed., Manual 20, 2nd ed., *Corrosion Tests and Standards: Application and Interpretation* (West Conshohocken, PA, USA: ASTM International, 2005), p. 280.

COMBINATIONS OF ALLOYS AND ENVIRONMENTS SUBJECT TO DEALLOYING

Alloy	Environment	Element Removed
Brasses	Many waters, especially under stagnant conditions	Zinc (dezincification)
Gray iron	Soils, many waters	Iron (graphitic corrosion)
Aluminum bronzes	Hydrofluoric acid, acids containing chloride ions	Aluminum (dealuminification)
Silicon bronzes	High-temperature steam and acidic species	Silicon (desiliconification)
Tin bronzes	Hot brine or steam	Tin (destannification)
Copper-nickel alloys	High heat flux and low water velocity (in refinery condenser tubes)	Nickel (denickelification)
Copper-gold single crystals	Ferric chloride	Copper
Nickel-copper	Hydrofluoric and other acids	Copper in some acids, and nickel in others
Gold alloys with copper or silver	Sulfide solutions, human saliva	Copper, silver
High-nickel alloys	Molten salts	Chromium, iron, molybdenum, and tungsten
Medium- and high-carbon steels	Oxidizing atmospheres, hydrogen at high temperatures	Carbon (decarburization)
Iron-chromium alloys	High-temperature oxidizing atmospheres	Chromium, which forms a protective film
Nickel-molybdenum alloys	Oxygen at high temperature	Molybdenum

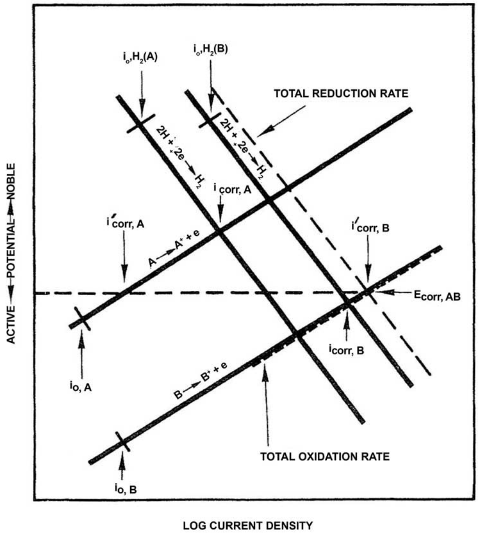
Source: L.J. Korb, *Metals Handbook*, 9th ed., Vol. 13 (Materials Park, OH, USA: ASM International, 1987), p. 130. Reprinted with permission from ASM International.

COMPARISON OF CREVICE CORROSION TESTS

Test	Summary
	(a) Non-Electrochemical Test
$FeCl_3$ Test, ASTM G 48, Method B	Maximum corrosion depth perpendicular to the crevice plane and/or mass-loss are measured after exposure of creviced specimens to 22˚C, 50˚C, or both. Crevice device is a TFE block without serrations. The test can provide qualitative ranking of an alloy's resistance with respect to type 304L SS, but is not adequate in ranking a number of corrosion resistant alloys. The rubber band holding the crevice blocks provide additional, uncontrolled crevice sites.
$FeCl_3$ + HCL Test, ASTM G 48, Method D	A serrated TFE crevice block is used and critical crevice temperature is determined through a series of tests at 5˚C increments. The test can be used to rank alloys. Test is limited to 85˚C because of instability of $FeCl_3$. The pitting resistance equivalents used to determine starting temperature can be misleading because they do not consider synergism between alloying elements. Critical crevice temperature is dependent on specimen preparation, test time, and solution composition.
Other solutions	A procedure similar to ASTM G 48 or ASTM G 78 should be followed.
	(b) Electrochemical Open-Circuit Potential Tests
Remote Crevice Assembly Test ASTM G 71 can be used for guidance	A sample with crevice block is electrically coupled to a larger open sample through a zero-resistance ammeter. The current flowing in the external circuit is an indicator of crevice activation and growth. It provides a more sensitive and continuous record of crevice initiation and growth processes. It simulates a real crevice condition. At present, there is no standard test procedure for this. Test time, area ratio of open to creviced sample are important factors.
	(c) Electrochemical Applied Potential/Current Tests
Critical Temperature Tests	The temperature is varied in steps or continuously while the potential is held at a constant value. The temperature at which a sustained increase in current is observed is noted as the critical temperature. While phenomenologically equivalent to ASTM G 48D, it provides greater freedom in choice of potential and sensitivity in current measurements.
Critical Potential Tests (ASTM G 61 and variants)	The potential can be scanned continuously or varied in a stepwise manner. The potential at which current increases during the upward scan or stepping of potential is called the initiation potential, E_{corr} or E_p. The potential at which current decreases to a low value during downward scan or stepping of potential is called repassivation potential, E_{corr} or E_p. The value of E_{corr} is independent of prior growth of crevice corrosion provided a sufficient extent of growth is maintained. For corrosion resistant alloys, too high an initial potential at which crevice corrosion is initiated is can result in erroneous measurement of E_{corr}.

Source: R. Baboian, ed., Manual 20, 2nd ed., *Corrosion Tests and Standards: Application and Interpretation* (West Conshohocken, PA, USA: ASTM International, 2005), p. 223.

POLARIZATION DIAGRAMS FOR A GALVANIC COUPLE (METALS A AND B)



Source: R. Baboian, ed., *Electrochemical Techniques for Corrosion Engineering* (Houston, TX, USA: NACE International, 1986), p. 257.

PRACTICAL GALVANIC SERIES

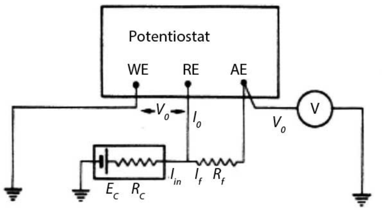
Open Circuit Potential Values Compared to Copper Alloy C11000
Test Medium: 5% NaCl at 25˚C, 2.5-4 m/s

UNS	Name	Condition	Voltage
M11311	AZ31B Mg		−1.344
M11912	AZ91B Mg		−1.314
Z33250	AG40A Zn		−0.786
–	Berylium		−0.780
A92014	2014Al	T3	−0.639
A91160	1160Al	H4	−0.609
A97075	7075Al	T6	−0.604
A97079	7079Al		−0.584
M08990	Uranium		−0.556
A95052	5052Al	H12	−0.545
A95052	5052Al	0	−0.534
A95083	5083Al		−0.524
A96151	6151Al	T6	−0.520
–	Cadmium		−0.519
A95456	5456Al		−0.514
A95456	5456Al	H343	−0.507
A94043	4043Al	H14	−0.507
A95052	5052Al	H32	−0.502
A91100	1100Al	0	−0.499
A93003	3003Al	H25	−0.496
A96061	6061Al	T6	−0.493
A97071	7071Al	T6	−0.484
A13800	1380Al	Cast	−0.444
A92014	2014Al	0	−0.444
A92024	2024Al	T4	−0.370
A95056	5056Al	H16	−0.369
S43000	430 SS	active	−0.324
–	Lead		−0.316
G10100	1010 steel		−0.297
C11000	ETP Copper		0.000 (ref.)
S34700	347 SS	active	+0.006
–	Molybdenum		+0.006
C71500	Cu-Ni, 70-30		+0.012
S20200	202 SS	active (dull)	+0.014
–	Niobium		+0.018
C53400	Phosphor Bronze		+0.034
S20200	202 SS	active (bright)	+0.051
N44000	400 Ni-Cu alloy		+0.051
S34700	347 SS	passive	+0.058
N02200	Nickel 200		+0.064
S20100	201 SS	active	+0.070
N08020	20Cb-3	active	+0.074
S32100	321 SS	active	+0.077
S31600	316 SS	active	+0.082
S30400	304 SS	passive	+0.098
S17700	17-7PH	passive	+0.098
S30900	309 SS	active	+0.108
S31000	310 SS	passive	+0.109
S30100	301 SS	passive	+0.112
S32100	321 SS	passive	+0.116
S20100	201 SS	passive	+0.129
S35500	AM 355	active	+0.167
S66286	A286	active	+0.156
S31603	316L SS	passive	+0.156
S20200	202 SS	passive (dull)	+0.159

UNS	Name	Condition	Voltage	UNS	Name	Condition	Voltage
–	Tin		−0.281	S35500	Am 355	active	+0.167
S41000	410 SS	active	−0.297	S20200	202 SS	passive	
–	Tantalum		−0.166			(bright)	+0.183
S35000	AM 350	active	−0.149	N08020	20Cb-3	passive	+0.186
R50255	Ta-W,90-10		−0.124	S35500	Am 355	passive	+0.204
S31000	310 SS	active	−0.124	S66286	A286	passive	+0.311
S30100	301 SS	active	−0.120	R54521	Ti, 5Al-2.5Sn		+0.423
S30400	304 SS	active	−0.106	R50810	Ti, 13V-1 1Cr-3Al		
S43000	430 SS	passive	−0.094			ANN (33.5 HRC)	+0.436
S17700	17-7PH	active	−0.076	R56401	Ti, 6Al-4V		
–	Tungsten		−0.047			STA (41.5 HRC)	+0.455
–	Niobium, 1% Zr		−0.044	–	Graphite		+0.473
C26800	Yellow brass		−0.043	R56401	Ti, 6Al-4V	ANN	
–	Uranium, 8% Mo		−0.041			(36 HRC)	+0.481
C46400	Naval brass		−0.041	R56080	Ti, 8Mn		+0.493
C28000	Muntz metal		−0.034	R50810	Ti, 13V-11	Cr-3Al	
C75200	Nickel silver		−0.022			STA (45.5 HRC)	+0.498
S31603	316L SS	active	−0013	R50700	Ti, Gr.	4 (75A)	+0.506
C22000	Bronze, 90%		−0.012	S35000	AM 350	passive	+0.666
C65500	Si Bronze A		−0.007				

Source: C.M. Forman, E.A. Verchot, “Practical Galvanic Series” U.S. Army Missile Command Report No. RS-TR-67-11, Redstone Arsenal, 1967.

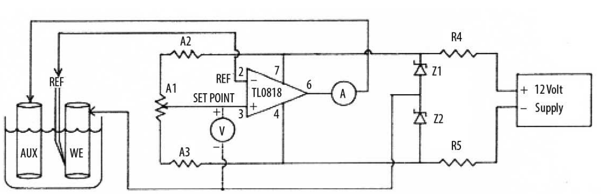
GALVANIC CORROSION TEST CIRCUIT USING A POTENTIOSTAT AS A ZERO-RESISTANCE AMMETER



Source: R. Baboian, ed., *Electrochemical Techniques for Corrosion Engineering* (Houston, TX, USA: NACE International, 1986), p. 255.

LOW COST POTENTIOSTAT CIRCUIT

Simple Potentiostatic Circuit with Single Output Power



PARTS

R1 – 100 k ohm, 10 turn potentiometer : typical (allen-bradley AT5L104)

A2, A3 – Resistor, 1/4 watt 100 k ohm 10% – lower values give wider set point range

A4, A5 – Resistor, 1/4 watt 100 ohm 10%

Z1, Z1 – 4.7 volt 400 nw Zener Diode (Texas Instruments Inc. #IN750)

Source: R. Baboian, P. Prew, “Low-Cost Electronic Devices for Corrosion Measurements,” *Materials Performance* 32, 7 (1993).

TYPICAL HIGH TEMPERATURE/HIGH PRESSURE TEST CONDITIONS

No.	Application	Environment	Temp, °C	Pressure, MPa (bar)
1	Nuclear Power	high-purity water/ steam/H_2	280 to 500	≤17 (170)
2	Fluidized Bed Combustion	air, gas, coal	600 to 750	1 (10)
3	Deep Sea	seawater	0 to 70*	<5 (50)
4	Oil and Gas Production	brine, H_2S, CO_2, S°	20 to 250	≤130 (1300)
5	Aerospace Propulsion	hydrogen oxygen H_2 , H_2S, hydrocarbons	−200 to 900 −200 to 480	0.1 to 67 (1 to 670)
6	Petroleum Refining		350 to 650	≤8 (80) ≤10 (100)
7	Compressed Natural Gas Storage	methane w/trace H_2S	0 to 100	≤8 (80)
8	Ammonia Storage	NH_3 , H_2O	0 to 70	≤4 (40)
9	Thermodynamic Power Generation	NH_3 , H_2O	100 to 650	1.5 to 11 (15 to 110)
10	Exhaust Gas Processing	H_2, N_2, CO, CO_2	≤70	≤35 (350)
11	Natural Gas Pipeline	CH_4 w/trace $H_2S/CO_2/O_2$	≤60	≤13 (130)
12	Geothermal Power	brine, steam, H_2S	≤370	≤17 (170)
13	Steam Boiler	water/steam	≤300	≤9 (90)

* Pipeline surface temperature.

Source: Manual 20, *Corrosion Tests and Standards: Application and Interpretation* (West Conshohocken, PA, USA: ASTM International, 1995), p. 106. Reprinted with permission, copyright ASTM.

CORROSION RATE CONVERSION FACTORS

$$\text{Mils/year (mpy)} = C \times \frac{\text{weight loss}}{\text{area} \times \text{time}} \times K$$

$$\text{Millimeters/year (mm/y)} = 0.0254 \text{ mpy}$$

Weight Loss	Area	C Factors: Hour	Day	Week	Month	Year
mg	cm^2	437	18.2	2.59	0.598	0.0498
	dm^2	4.37	0.182	0.0259	5.98×10^{-3}	4.98×10^{-4}
	m^2	0.0437	1.82×10^{-3}	2.59×10^{-4}	5.98×10^{-5}	4.98×10^{-6}
	$in.^2$	67.7	2.82	0.402	0.0927	7.72×10^{-3}
	$ft.^2$	0.470	0.0196	2.79×10^{-3}	6.44×10^{-4}	5.36×10^{-5}
g	cm^2	437×10^3	182×10^2	2590	598	49.8
	dm^2	4370	182	25.9	5.98	0.498
	m^2	43.7	1.82	0.259	0.0598	4.98×10^{-3}
	$in.^2$	677×10^2	2820	402	92.7	7.72
	$ft.^2$	470	19.6	2.79	0.644	0.0536
lb.	cm^2	198×10^6	825×10^4	118×10^4	271×10^3	226×10^2
	dm^2	198×10^4	825×10^2	118×10^2	2710	226
	m^2	198×10^2	825	118	27.1	2.26
	$in.^2$	307×10^5	128×10^4	182×10^3	420×10^2	3,500
	$ft.^2$	213×10^3	8,880	1270	292	24.3

EXAMPLE: A 5.0 square inch specimen of copper has a weight loss of 218 mg in a 40 hour corrosion test.

$$\text{mpy} = 67.7 \times 218/(5.0 \times 4.0) \times 0.88 = 65$$

$$\text{mm/y} = 0.0254 \times 65 = 1.65$$

K is a density factor.
K = 1.000 for carbon steel.
K factors for other alloys are given on the next page.

Source: Aaron Wachter.

DENSITIES OF COMMON ALLOYS

(K = ratio of carbon steel density to that of alloy)

UNS	Common Name	Density g/cm³	K	UNS	Common Name	Density g/cm³	K
A91100	Al 1100	2.72	2.89	N06007	G Alloy	8.34	0.94
A93003	Al 3003	2.74	2.87	N06022	C-22 Alloy	8.69	0.90
A95052	Al 5052	2.68	2.93	N06030	G-30 Alloy	8.22	0.96
A96061	Al 6061	2.70	2.91	N06455	C-4 Alloy	8.64	0.91
A97075	Al 7075	2.80	2.81	N06600	600 Alloy	8.47	0.93
C11000	ETP Copper	8.94	0.88	N06601	601 Alloy	8.11	0.97
C22000	Commercial Bronze	8.89	0.88	N06625	625 Alloy	8.44	0.93
C23000	Red Brass	8.75	0.90	N06985	G-3 Alloy	8.30	0.95
C26000	Cartridge Brass	8.53	0.92	N07001	Waspaloy	8.19	0.96
C27000	Yellow Brass	8.39	0.94	N07041	Rene 41	8.25	0.95
C28000	Muntz Metal	8.39	0.94	N07718	718 Alloy	8.19	0.96
C44300	Admiralty brass. As	8.52	0.92	N07750	X-750 Alloy	8.28	0.95
C46500	Naval Brass. As	8.41	0.93	N08020	20Cb-3	8.08	0.97
C51000	Phosphor Bronze A	8.86	0.89	N08024	20Mo-4	8.11	0.97
C52400	Phosphor Bronze D	8.78	0.90	N08026	20Mo-6	8.13	0.97
C61300	Aluminum Bronze, 7%	7.89	1.00	N08028	Sanicro 28	8.0	0.98
C61400	Aluminum Bronze D	7.78	1.01	N08366	AL-6X	8.0	0.98
C63000	Ni-Al Bronze	7.58	1.04	N08800	800 Alloy	7.94	0.99
C65500	High-Silicon Bronze	8.52	0.92	N08825	825 Alloy	8.14	0.97
C67500	Manganese Bronze A	8.36	0.94	N08904	904L Alloy	8.0	0.98
C68700	Aluminum Brass, As	8.33	0.94	N08925	25-6Mo	8.1	0.97
C70600	9-10 Copper-Nickel	8.94	0.88	N09925	925 Alloy	8.05	0.98
C71500	70-30 Copper-Nickel	8.94	0.88	N10003	N Alloy	8.79	0.89
C75200	Nickel Silver	8.73	0.90	N10004	W Alloy	9.03	0.87
C83600	Ounce Metal	8.80	0.89	N10276	C-276 Alloy	8.89	0.88
C86500	Manganese Bronze	8.3	0.95	N10665	B-2 Alloy	9.22	0.85
C90500	Gun Metal	8.72	0.90	R03600	Molybdenum	10.22	0.77

UNS	Common Name	Density g/cm^3	K	UNS	Common Name	Density g/cm^3	K
C92200	M Bronze	8.64	0.91	R04210	Niobium	8.57	0.92
C95700	Cast Mn-Ni-Al Bronze	7.53	1.04	R05200	Tantalum	16.60	0.47
C95800	Cast Ni-Al Bronze	7.64	1.03	R50250	Titanium, Gr 1	4.54	1.73
F10006	Gray Cast Iron	7.20	1.09	R50400	Titanium, Gr 2	4.54	1.73
F20000	Malleable Cast Iron	7.27	1.08	R53400	Titanium, Gr 12	4.52	1.74
F32800	Ductile Iron	7.1	1.11	R56400	Titanium, Gr 5	4.43	1.77
F41002	Ni-Resist Type 2	7.3	1.08	R60702	Zr 702	6.53	1.20
F43006	Ductile Ni-Resist, D5	7.68	1.02	S20100	201 SS	7.94	0.99
F47003	Duriron	7.0	1.12	S20200	202 SS	7.94	0.99
G10200	1020 Carbon Steel	7.86	1.00	S30400	304 SS	7.94	0.99
G41300	4130 Steel	7.86	1.00	S30403	304L SS	7.94	0.99
J91150	CA-15 Cast SS	7.61	1.03	S30900	309 SS	7.98	0.98
J91151	CA-15M Cast SS	7.61	1.03	S31000	310 SS	7.98	0.98
J91540	CA-6NM Cast SS	7.7	1.02	S31254	254 SMO	8.0	0.98
J92600	CF-8 Cast SS	7.75	1.01	S31500	3RE60	7.75	1.01
J92800	CF-3MN Cast SS	7.75	1.01	S31600	316 SS	7.98	0.98
J92900	CF-8M Cast SS	7.75	1.01	S31603	316L SS	7.98	0.98
J94204	HK-40 Cast SS	7.75	1.01	S31700	317 SS	7.98	0.98
J95150	CN-7M Cast SS	8.00	0.98	S32100	321 SS	7.94	0.99
K11597	1.25Cr-0.5Mo Steel	7.85	1.00	S32550	Ferralium 255	7.81	1.01
K81340	9Ni Steel	7.86	1.00	S32950	7 Mo Plus	7.75	1.01
L51120	Chemical Lead	11.3	0.70	S34700	347 SS	8.03	0.98
M11311	Mg AZ31B	1.77	4.44	S41000	410 SS	7.70	1.02
N02200	Nickel 200	8.89	0.88	S43000	430 SS	7.72	1.02
N04400	400 Alloy	8.80	0.89	S44600	446 SS	7.65	1.03
N05500	K-500 Alloy	8.44	0.93	S50100	5Cr-0.5Mo Steel	7.82	1.01
N06002	X Alloy	8.23	0.96	S50400	9Cr-1Mo Steel	7.67	1.02

DENSITY OF MATERIALS

Material	Density (g/cm^3)	Density ($lb./in.^3$)	Material	Density (g/cm^3)	Density ($lb./in.^3$)
Iridium	22.65	0.82	Nickel iron superalloy	7.86	0.28
Osmium	22.61	0.82	Chromium steel	7.83	0.28
Platinum	21.45	0.77	Nonresulfurized carbon steel	7.83	0.28
Rhenium	21.00	0.76	Stainless steel (17Cr-4Ni)	7.81	0.28
Tungsten	19.40	0.70	Hot work tool steel	7.75	0.28
Gold	19.30	0.70	Aluminum bronze	7.64	0.28
Uranium	19.07	0.69	Babbitt	7.50	0.27
Tungsten carbide	17.20	0.62	Samarium	7.49	0.27
Tantalum	16.60	0.60	Manganese	7.43	0.27
Tantalum carbide (TaC)	14.53	0.52	Indium	7.31	0.26
Hafnium	13.10	0.47	Niobium nitride	7.30	0.26
Ruthenium	12.45	0.45	Tin	7.30	0.26
Rhodium	12.41	0.45	Cerium dioxide	7.28	0.26
Palladium	12.02	0.43	Austempered ductile iron	7.20	0.26
Thallium	11.85	0.43	Pewter (Sn, Sb, Cu)	7.20	0.26
Thorium	11.50	0.42	Chromium	7.19	0.26
Lead	11.34	0.41	Zinc	7.13	0.26
Silver	10.49	0.38	Neodymium	7.00	0.25
Molybdenum	10.20	0.37	Praseodymium	6.77	0.24
Bismuth	9.80	0.35	Cerium	6.77	0.24
Thulium	9.31	0.34	Chromium carbide	6.70	0.24
Cast high leaded tin bronze	9.29	0.34	Antimony	6.65	0.24
Nickel-moly (Hastelloy B-2)	9.20	0.33	Zirconium	6.49	0.23
Copper	8.96	0.32	Lanthanum	6.15	0.22
Nickel	8.90	0.32	Vanadium	6.11	0.22
Copper nickel (64Cu-14Ni-22Zn)	8.85	0.32	Nickel aluminide (NiAl)	6.05	0.22
			Gallium	5.91	0.21
Cobalt	8.85	0.32	Zirconia (partially stabilized)	5.70	0.21
Nickel silver	8.70	0.31	Germanium	5.32	0.19
Brass (61.5Cu-3Pb-35.5Zn)	8.70	0.31	Germanium	5.32	0.19
Brass (61.5Cu-3Pb-35.5Zn)	8.70	0.31	Titanium nitride	5.29	0.19
Bronze (57Cu, 40Zn, 3Pb)	8.70	0.31			

Material	Density (g/ cm^3)	Density (lb./ $in.^3$)	Material	Density (g/ cm^3)	Density (lb./ $in.^3$)
Cadmium	8.65	0.31	Titanium carbide	4.94	0.18
Niobium (Columbium)	8.57	0.31	Titanium diboride	4.52	0.16
Nickel chromium cobalt alloy	8.21	0.30	Titanium	4.51	0.16
Nickel chromium (Inconel 718)	8.20	0.30	Ti-6Al-4V	4.50	0.16
Copper zinc alloy	8.19	0.30	Titanium dioxide	4.25	0.15
Maraging steel	8.02	0.29	Aluminum oxide	3.98	0.14
Austenitic stainless steel	8.00	0.29	Spinel (MgO·Al3 O3)	3.57	0.13
Iron-nickel (Invar)	8.00	0.29	Aluminum nitride	3.26	0.12
Iron	7.87	0.28	Sialon	3.20	0.12
Silicon nitride	3.19	0.12	Magnesium	1.74	0.06
Mullite ($3Al_2O_3$-$2SiO_2$)	3.16	0.11	PPS (polyphenylene sulfide)	1.67	0.06
Silicon carbide	3.10	0.11	Nylon 6	1.64	0.06
Hydroxyapatite	3.10	0.00	Acetal resin	1.57	0.06
Aluminum carbide	2.99	0.11	Epoxy resin	1.56	0.06
Wollastonite	2.90	0.10	Calcium	1.55	0.06
Aluminum copper alloy	2.84	0.10	Rubidium	1.53	0.06
Aluminum zinc alloy	2.78	0.10	Polycarbonate	1.53	0.06
Aluminum	2.70	0.10	Aramid fiber	1.45	0.05
Cordierite	2.65	0.10	Aromatic polyamide	1.44	0.05
E-glass fiber	2.62	0.10	Bismaleimide resin	1.36	0.05
Pyrex glass	2.52	0.09	Silicone	1.35	0.05
Boron carbide	2.52	0.09	PEEK (polyetheretherketone)	1.32	0.05
Boron	2.40	0.09	Cellulose acetate	1.30	0.05
Silicon	2.33	0.08	Human Bone	1.30	0.05
PTFE (polytetrafluoroethylene)	2.30	0.08	Polyurethane	1.27	0.05
Graphite	2.26	0.08	ABS (acrylonitrile butadiene styrene)	1.26	0.05
Boron nitride	2.25	0.08	Polysulfone	1.24	0.04
Sulfur	2.07	0.07	Acrylic	1.19	0.04
Unsaturated polyester	2.00	0.07	Polypropylene	1.05	0.04
Polyimide thermoset	2.00	0.07	Sodium	0.97	0.04
Phenolic resin	1.99	0.07	PE (polyethylene)	0.95	0.03
Beryllium	1.85	0.07	UHMWPE (ultrahigh molecular weight PE)	0.93	0.03
Phosphorus	1.83	0.07	Potassium	0.86	0.03
Carbon fiber	1.74	0.06	Lithium	0.53	0.19

Source: GEM 2001, "Guide to Engineering Materials: Advanced Materials and Processes" (Materials Park, OH, USA: ASM International, 2000), p. 35. Reprinted with permission from ASM International .

EQUIVALENT WEIGHT VALUES FOR METALS AND ALLOYS

			Lowest		Second		Third		Fourth	
Common Designation	**UNS**	**Elements w/Constant Valence**	**Variable Valence**	**Equivalent Weight**	**Variable Valance**	**Equivalent Weight**	**Element/ Valence**	**Equivalent Weight**	**Element/ Valence**	**Equivalent Weight**
Aluminum Alloys										
AA1100	A91100	Al/3		8.99						
AA2024	A92024	Al/3, Mg/2	Cu/1	9.38	Cu/2	9.32				
AA2219	A92219	Al/3	Cu/1	9.51	Cu/2	9.42				
AA3003	A93003	Al/3	Mn/2	9.07	Mn/4	9.03	Mn 7	8.98		
AA3004	A93004	Al/3, Mg/2	Mn/2	9.09	Mn/4	9.06	Mn 7	9.00		
AA5005	A95005	Al/3, Mg/2		9.01						
AA5050	A95050	Al/3, Mg/2		9.03						
AA5052	A95052	Al/3, Mg/2		9.05						
AA5083	A95083	Al/3, Mg/2		9.09						
AA5086	A95086	Al/3, Mg/2		9.09						
AA5154	A95154	Al/3, Mg/2		9.08						
AA5454	A95454	Al/3, Mg/2		9.06						
AA5456	A95456	Al/3, Mg/2		9.11						
AA6061	A96061	Al/3, Mg/2		9.01						

			Lowest		Second		Third		Fourth	
Common Designa-tion	**UNS**	**Elements w/Constant Valence**	**Variable Valence**	**Equivalent Weight**	**Variable Valance**	**Equivalent Weight**	**Element/ Valence**	**Equivalent Weight**	**Element/ Valence**	**Equivalent Weight**
AA6070	A96070	Al/3,Mg/2, Si/4		8.98						
AA6101	A96161	Al/3		8.99						
AA7072	A97072	Al/3, Zn/2		9.06						
AA7075	A97075	Al/3, Zn/2, Mg/2	Cu/1	9.58	Cu/2	9.55				
AA7079	A97079	Al/3, Zn/2, Mg/2		9.37						
AA7178	A97178	Al/3, Zn/2, Mg/2	Cu/1	9.71	Cu/2	9.68				
Copper Alloys										
CDA110	C11000		Cu/1	63.55	Cu/2	31.77				
CDA220	C22000	Zn/2	Cu/1	58.07	Cu/2	31.86				
CDA230	C23000	Zn/2	Cu/1	55.65	Cu/2	31.91				
CDA260	C26000	Zn/2	Cu/1	49.51	Cu/2	32.04				
CDA280	C28000	Zn/2	Cu/1	46.44	Cu/2	32.11				
CDA444	C44300	Zn/2	Cu/1, Sn/2	50.42	Cu/1, Sn/4	50.00	Cu/2, Sn/4	32.00		
CDA687	C68700	Zn/2, Al/3	Cu/1	48.03	Cu/2	30.29				

			Lowest		Second		Third		Fourth	
Common Designation	UNS	Elements w/Constant Valence	Variable Valence	Equivalent Weight	Variable Valance	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
CDA608	C60800	Al/3	Cu/1	47.114	Cu/2	27.76				
CDA510	C51000		Cu/1, Sn/2	63.32	Cu/1, Sn/4	60.11	Cu/2, Sn/4	31.66		
CDA524	C52400		Cu/1, Sn/2	63.10	Cu/1, Sn/4	57.04	Cu/2, Sn/4	31.55		
CDA655	C65500	Si/4	Cu/1	50.21	Cu/2	28.51				
CDA706	C70600	Ni/2	Cu/1	56.92	Cu/2	31.51				
CDA715	C71500	Ni/2	Cu/1	46.69	Cu/2	30.98				
CDA752	C75200	Ni/2, Zn/2	Cu/1	46.38	Cu/2	31.46				
Stainless Steels										
304	S30400	Ni/2	Fe/2, Cr/3	25.12	Fe/3, Cr/3	18.99	Fe/3, Cr/6	15.72		
321	S32100	Ni/2	Fe/2, Cr/3	25.13	Fe/3, Cr/3	19.08	Fe/3, Cr/6	15.78		
309	S30900	Ni/2	Fe/2, Cr/3	24.62	Fe/3, Cr/3	19.24	Fe/3, Cr/6	15.33		
310	S31000	Ni/2	Fe/2, Cr/3	24.44	Fe/3, Cr/3	19.73	Fe/3, Cr/6	15.36		
316	S31600	Ni/2	Fe/2, Cr/3, Mo/3	25.50	Fe/3, Cr/3, Mo/4	25.33	Fe/3, Cr/6, Mo/6	19.14	Fe/3, Cr/6, Mo/6	16.111

			Lowest		Second		Third		Fourth	
Common Designation	UNS	Elements w/Constant Valence	Variable Valence	Equivalent Weight	Variable Valance	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
317	S31700	Ni/2	Fe/2, Cr/3, Mo/3	25.26	Fe/3, Cr/3, Mo/4	25.03	Fe/3, Cr/6, Mo/6	19.15	Fe/3, Cr/6, Mo/6	15.82
410	S41000		Fe/2, Cr/3	25.94	Fe/3, Cr/3	18.45	Fe/3, Cr/6	16.28		
430	S43000		Fe/2, Cr/3	25.30	Fe/3, Cr/3	18.38	Fe/3, Cr/6	15.58		
446	S44600		Fe/2, Cr/3	24.22	Fe/3, Cr/3	18.28	Fe/3, Cr/6	14.46		
20CB3[a]	N08020	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	23.98	Fe/2, Cr/3, Mo/4, Cu/1	23.83	Fe/3, Cr/3, Mo/6, Cu/2	18.88	Fe/3, Cr/6, Mo/6, Cu/2	15.50
Nickel Alloys										
200	N02200		Ni/2	29.36	Ni/3	19.57				
400	N04400	Ni/2	Cu/1	35.82	Cu/2	30.12				
600	N06600	Ni/2	Fe/2, Cr/3	26.41	Fe/3, Cr/3	25.44	Fe/3, Cr/6	20.73		
800	N08800	Ni/2	Fe/2, Cr/3	25.10	Fe/3, Cr/3	20.76	Fe/3, Cr/6	16.59		
825	N08825	Ni/2	Fe/2, Cr/3, Mo/3, Cu/1	25.52	Fe/3, Cr/3, Mo/4, Cu/1	25.32	Fe/3, Cr/3, Mo/6, Cu/2	21.70	Fe/3, Cr/6, Mo/6, Cu/2	17.10
B	N10001	Ni/2	Mo/3, Fe/2	30.05	Mo/4, Fe/2	27.50	Mo/6, Fe/2	23.52	Mo/6, Fe/3	23.23

			Lowest		Second		Third		Fourth	
Common Designa-tion	**UNS**	**Elements w/Constant Valence**	**Variable Valence**	**Equivalent Weight**	**Variable Valance**	**Equivalent Weight**	**Element/ Valence**	**Equivalent Weight**	**Element/ Valence**	**Equivalent Weight**
C-22[b]	N06022	Ni/2	Fe/2, Cr/3, Mo/3, W/4	26.04	Fe/2, Cr/3, Mo/4,W/4	25.12	Fe/2, Cr/3, Mo/6,W/6	23.28	Fe/3, Cr/6, Mo/6,W/6	17.88
C-276	N10276	Ni/2	Fe/2, Cr/3, Mo/3, W/4	27.09	Cr/3, Mo/4	25.90	Fe/2, Cr/3, Mo/6, W/6	23.63	Fe/3, Cr/6, Mo/6, W/6	19.14
G	N06007	Ni/2	(1)	25.46	(2)	22.22	(3)	22.04	(4)	17.03
Carbon Steel			Fe/2	27.92	Fe/3	18.62				
Other Metals										
Mg	M14142	Mg/2		12.15						
Mo	R03600		Mo/3	31.98	Mo/4	23.98	Mo/6	15.99		
Ag	P07016		Ag/1	107.87	Ag/2	53.93				
Ta	R05210	Ta/5		36.19						
Sn	L13002		Sn/2	59.34	Sn/4	29.67				

(1) = Fe/2, Cr/3, Mo/3, Cu/1, Nb/4, Mn/2
(2) = Fe/2, Cr/3, Mo/4, Cu/2, Nb/5, Mn/2
(3) = Fe/3, Cr/3, Mo/6, Cu/2, Nb/5, Mn/2
(4) = Fe/3, Cr/6, Mo/6, Cu/2, Nb/5, Mn/4

			Lowest		Second		Third		Fourth	
Common Designation	UNS	Elements w/Constant Valence	Variable Valence	Equivalent Weight	Variable Valance	Equivalent Weight	Element/ Valence	Equivalent Weight	Element/ Valence	Equivalent Weight
Ti	R50400		Ti/2	23.95	Ti/3	15.97	Ti/4	11.98		
Zn	Z19001	Zn/2		32.68						
Zr	R60701	Zr/4		22.80						
Pb	L50045		Pb/2	103.59	Pb/4	51.80				

(a) Registered trademark Carpenter Technology.

(b) Registered trademark Haynes International.

Note 1: Alloying elements at concentrations below 1% by mass were not included in the calculation, for example, they were considered part of the basis metal.

Note 2: Midrange values were assumed for concentrations of alloying elements.

Note 3: Only consistent valence groupings were used.

Note 4: Equation 4 in ASTM G102 was used to make these calculations.

Source: ASTM G102, "Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements" (West Conshohocken, PA, USA: ASTM International, 2000). Reprinted with permission, copyright ASTM.

CORROSION RATE CALCULATION FROM MASS LOSS

$$\text{Corrosion rate} = \frac{(K \times W)}{(A \times T \times D)}$$

where

K = a constant (see below),

T = time of exposure in hours to the nearest 0.01 h,

A = area in cm^2 to the nearest 0.01 cm^2,

W = mass loss in g, to nearest 1 mg (corrected for any loss during cleaning (see 9.4), and

D = density in g/cm^3.

Many different units are used to express corrosion rates. Using the above units for T, A, W, and D, the corrosion rate can be calculated in a variety of units with the following appropriate value of K:

Constant (K) in Corrosion	Corrosion Rate Units Desired Rate Equation
mils per year (mpy)	3.45×10^6
inches per year (ipy)	3.45×10^3
inches per month (ipm)	2.87×10^2
millimeters per year (mm/y)	8.76×10^4
micrometers per year (µm/y)	8.76×10^7
picometers per second (pm/s)	2.78×10^6
grams per square meter per hour ($g/m^2 \cdot h$)	$1.00 \times 10^4 \times D$[a]
milligrams per square decimeter per day (mdd)	$2.40 \times 10^6 \times D$[a]
micrograms per square meter per second ($\mu g/m^2 \cdot s$)	$2.78 \times 10^6 \times D$[a]

[a] Density is not needed to calculate the corrosion rate in these units. The density in the constant K cancels out the density in the corrosion rate equation.

Source: ASTM G1, "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens" (West Conshohocken, PA, USA: ASTM International, 2000). Reprinted with permission, copyright ASTM.

VALUES OF CONSTANTS FOR USE IN FARADAY'S EQUATION

Calculation of Corrosion Rate—Faraday's Law can be used to calculate the corrosion rate, either in terms of penetration rate (*CR*) or mass loss rate (*MR*)

$$CR = K_1 \frac{i_{corr}}{\rho} EW$$

$$MR = K_2 \, i_{corr} \, EW$$

where

CR is given in mm/yr, i_{corr} in µA/cm², $K1 = 3.27 \times 10^{-3}$, mm g/µA cm yr, ρ = density in g/cm³,

$MR = g/m^2 d$, and

$K_2 = 8.954 \times 10^{-3}$, g cm²/µA m² d.

EW = Equivalent weight

Other values for K_1 and K_2 for different unit systems are given in the following table:

Rate

A

Penetration Rate Unit (CR)	I_{corr} Unit	ρ Unit	K_1	Units of K_1 [a]
mpy	µA/cm²	g/cm³	0.1288	mpy g/µA cm
mm/yr.[b]	A/m²[b]	kg/m³[b]	327.2	mm kg/A my
mm/yr.[b]	µA/cm²	g/cm³	3.27×10^{-3}	mm g/µA cmy

B

Mass Loss Rate Unit	I_{corr} Unit	K_2	Units of K_2 [a]
g/m² d[b]	A/m²[b]	0.8953	g/Ad
mg/dm² d (mdd)	µA/cm²	0.0895	mg cm²/µA dm² d
mg/dm² d (mdd)	A/m²[b]	8.953×10^{-3}	mg m²/A dm² d

[a] EW is assumed to be dimensionless.
[b] SI unit.

Source: ASTM G102, "Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements" (West Conshohocken, PA, USA: ASTM International, 2000). Reprinted with permission, copyright ASTM.