

# Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K

Steven G. Bratsch

Department of Chemistry, Southwest Texas State University, San Marcos, Texas 78666

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A great deal of solution chemistry can be summarized in a table of standard electrode potentials of the elements in the solvent of interest. In this work, standard electrode potentials and temperature coefficients in water at 298.15 K, based primarily on the "NBS Tables of Chemical Thermodynamic Properties," are given for nearly 1700 half-reactions at  $pH = 0.000$  and  $pH = 13.996$ . The data allow the calculation of the thermodynamic changes and equilibrium constants associated with  $\sim 1.4$  million complete cell reactions over the normal temperature range of liquid water. Estimated values are clearly distinguished from experimental values, and half-reactions involving doubtful chemical species are duly noted. General and specific methods of estimation of thermodynamic quantities are summarized.

**Key words:** electrochemical cell reaction; equilibrium constant; half-reaction; standard electrode potential; standard enthalpy, entropy and Gibbs energy change; temperature coefficient; third-law entropy

## Contents

1. Introduction .....	1	6. Thermodynamic Properties of Individual Chemical Species.....	17
2. Sources of Thermodynamic Data .....	2	7. Calculations for Nonstandard Conditions .....	17
3. Limitations and Scope; Formula Writing .....	16	8. Second Temperature Coefficients .....	18
4. Standard Electrode Potentials of Half-Reactions and Complete Cell Reactions .....	16	9. Estimated Values .....	19
5. Thermodynamic Changes Associated with Half-Reactions and Complete Cell Reactions .....	17	10. References .....	21

## List of Tables

1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K .....	3
2. Third-Law Standard Entropies at 298.15 K .....	18
3. Second Temperature Coefficients at 298.15 K .....	19

## 1. Introduction

A standard electrode potential  $E^{\circ}$  is defined as the potential (in volts, V) of a half-reaction relative to a reference electrode at a specified temperature, all chemical species being in their standard states at unit activity. These states may be arbitrarily defined as pure crystalline solids, pure liquids, ideal gases at one atmosphere fugacity ( $1.013\ 25 \times 10^5$  Pa), and ideal solutes at unit molality. The most common tem-

perature for the tabulation of standard electrode potentials, as for other thermodynamic data, is 25 °C (298.15 K).

For the solvent water, the usual reference electrode is the standard hydrogen electrode (SHE),  $E^{\circ}$  for the half-reaction



being assigned a value of zero volts at all temperatures. The SHE may be abbreviated as  $E^{\circ}[\text{H}^{+}/\text{H}_2(\text{g})]$ . The symbol  $e^{-}$  in a conventional half-reaction represents one electrochemical equivalent (i.e., one mole of electrons).

The classic reference for standard electrode potentials in water is Latimer's "Oxidation Potentials,"<sup>1</sup> which provides  $E^{\circ}$  values for a large number of half-reactions at 298.15 K. de Bethune and others<sup>2-4</sup> have shown that the temperature dependence of  $E^{\circ}$  is approximately linear between 273.15 and 373.15 K, and have extended Latimer's work over the normal temperature range of liquid water by tabulating temperature coefficients of standard electrode potentials  $dE^{\circ}/dT$ :

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$$E^0_T = E^0_{298} + (T - 298.15) \cdot \left( \frac{dE^0}{dT} \right)_{298} \quad (2)$$

Temperature coefficients may be conveniently expressed in millivolts per kelvin, mV/K. As with  $E^0$  values,  $dE^0/dT$  values are defined relative to  $dE^0/dT$  for the SHE being equal to zero at all temperatures. The accuracy of Eq. (2) depends on the assumption that  $E^0$  is a linear function of temperature. This is not quite true, although the errors incurred are often small. Deviations from linearity are discussed in Sec. 8.

The works of Latimer<sup>1</sup> and de Bethune *et al.*<sup>2-4</sup> have been widely quoted. Unfortunately, however, their primary reference is the Circular 500 of the United States National Bureau of Standards (NBS),<sup>5</sup> now, the National Institute of Standards and Technology (NIST), which has been rendered obsolete through modern publications by the Institute.<sup>6,7</sup> The need exists for a table of standard electrode potentials and temperature coefficients in water at 298.15 K which is based on the modern NBS tables.

## 2. Sources of Thermodynamic Data

Standard electrode potentials and temperature coefficients at 298.15 K are presented in Table 1. The elements are arranged by Periodic Table family for easy access. The primary sources of thermodynamic data used in this report are the "NBS Technical Note 270" series<sup>6</sup> and the "NBS Tables of Chemical Thermodynamic Properties."<sup>7</sup> The data tabulated in Refs. 6 and 7 are not yet supported by a published bibliography; information about the selection of thermodynamic values for specific chemical species may be obtained by writing to the Director, Chemical Thermodynamics Data Center, Room A158, Chemistry Building, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899. Reference 7 contains a detailed discussion of the problems of internal consistency encountered when combining thermodynamic data from different sources. In this report, an attempt has been made to keep non-NIST sources to a minimum, calling upon them only when the values are clearly superior to NIST, or when NIST provides no data.

Auxiliary references which provide much data not given by NIST are "The Hydrolysis of Cations" by Baes and Mesmer,<sup>8(a)</sup> a follow-up paper by the same authors,<sup>8(b)</sup> and "Standard Potentials in Aqueous Solution," edited by Bard, Parsons, and Jordan.<sup>9</sup> (For reasons discussed below, the latter reference has been used with discretion.) Some thermodynamic data used in this report have been taken from "Advanced Inorganic Chemistry" by Cotton and Wilkinson,<sup>10</sup> but this popular text has served mainly as a rich source of descriptive chemistry for the estimation of thermodynamic quantities (*vide infra*). Thermodynamic prediction methods developed by the author<sup>11-13</sup> have aided in the compilation of standard electrode potentials and temperature coefficients of the lanthanides and actinides, and, with appropriate modification, for a few other elements. Thirteen standard Gibbs energies of formation and eight standard entropies (none of which has been superseded by NBS<sup>6,7</sup>) have been taken or deduced from Latimer.<sup>1</sup> The standard enthalpy of formation of  $\text{FeO}_4^{2-}$  has been taken from de Bethune *et al.*<sup>2</sup>

## 2.1. Uncertainties

Following NBS,<sup>6,7</sup> the probable uncertainties associated with the  $E^0$  and  $dE^0/dT$  values in this report are implied by the number of digits tabulated.  $E^0$  and  $dE^0/dT$  values in Table 1 are believed to be uncertain by less than ten units in the last digit tabulated. For experimentally based values, the number of digits tabulated reflects the cumulative uncertainties in the thermodynamic data. For estimated values (enclosed in parentheses), the number of digits tabulated reflects the uncertainty in the method of prediction (*vide infra*). The author accepts full responsibility for all estimated values in this report.

It is necessary to discuss Ref. 9 in some detail at this point, because ostensibly it has already accomplished the goal of this report. (However, the present work contains many more temperature coefficients of electrode potentials than does Ref. 9.) It can be verified from personal experience that it is a colossal undertaking to assemble a critically evaluated table of thermodynamic data for inorganic compounds; the approach taken by Bard *et al.*<sup>9</sup> has been to divide the work among several chapter authors. Unfortunately, some of the authors have taken or deduced  $E^0$  and/or  $dE^0/dT$  values from Latimer,<sup>1</sup> de Bethune *et al.*,<sup>2-4</sup> and the NBS Circular 500,<sup>5</sup> although such values have been superseded by the more recent NIST publications.<sup>6,7</sup> The following chapters in Ref. 9 contain extensive tables of such outdated values: Chap. 5 ( $E^0$  and  $dE^0/dT$  for F and  $E^0$  for I); Chap. 6 ( $dE^0/dT$  for S-Te); Chap. 7 ( $E^0$  for N and P); Chap. 8 ( $E^0$  and  $dE^0/dT$  for C-Pb); Chap. 9 ( $E^0$  and  $dE^0/dT$  for Ga and Ti); Chap. 17 ( $E^0$  for Nb and Ta); Chap. 18 ( $E^0$  for Ti-Hf); Chap. 22 ( $dE^0/dT$  for Mg-Ra); Chap. 23 ( $E^0$  and  $dE^0/dT$  for Li-Cs). Admittedly, in some cases, the absolute differences between the old<sup>1-5</sup> and new<sup>6,7</sup>  $E^0$  or  $dE^0/dT$  values are less than the sums of their assigned uncertainties. However, it would appear that a simple retabulation of the old values undermines the primary objective of Ref. 9, which can be construed from the preface as "to incorporate a wealth of new data in order to provide critically selected values and the best estimates now available."

On the other hand, over 100 of the  $E^0$  values in Ref. 9 differ significantly from the values listed in Table 1. Examples include  $E^0 [\text{Te(c)}, \text{H}^+/\text{H}_2\text{Te}] = -0.740 \text{ V}$  (Table 1:  $-0.46 \text{ V}$ );  $E^0 [\text{N}_2(\text{g}), \text{H}^+/\text{HN}_3] = -3.10 \text{ V}$  (Table 1:  $-3.334 \text{ V}$ );  $E^0 [\text{H}_2\text{SiO}_4^{2-}/\text{Si(c)}, \text{OH}^-] = -1.69 \text{ V}$  (Table 1:  $-1.834 \text{ V}$ );  $E^0 [\text{Ta}_2\text{O}_5 | (\text{c}, \beta), \text{H}^+/\text{Ta(c)}] = -0.81 \text{ V}$  (Table 1:  $-0.752 \text{ V}$ );  $E^0 [\text{Ti(OH)}_2^{2+}, \text{H}^+/\text{Ti(c)}] = -0.86 \text{ V}$  (Table 1:  $-1.00 \text{ V}$ ), and  $E^0 [\text{Cs}^+/\text{Cs(c)}] = -2.923 \text{ V}$  (Table 1:  $-3.026 \text{ V}$ ). The application of Latimer's equilibrium data<sup>1</sup> on  $\text{H}_2\text{Te}$ ,  $\text{H}_2\text{SiO}_4^{2-}$ , and  $\text{Ti(OH)}_2^{2+}$  to the modern NBS tables<sup>6,7</sup> instead of to the NBS Circular 500<sup>5</sup> yields  $E^0$  values in essential agreement with Table 1; the other  $E^0$  values in Table 1 (involving  $\text{HN}_3$ ,  $\text{Ta}_2\text{O}_5$ , and  $\text{Cs}^+$ ) have been calculated directly from the modern NBS tables.

Some of the data in Ref. 9 disagree with that in Table 1 because they have been calculated or assigned incorrectly. For example, the  $E^0$  values given for those vanadium species which predominate in basic solution (p. 523) have been calculated for unit activity  $\text{H}^+$  (aq) and are 0.8–2.9 V more

## STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

3

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Hydrogen<sup>6, 7</sup></b>					
H <sup>+</sup> / H <sub>2</sub> (g)	0.0000	0.0000	H <sub>2</sub> O (liq) / H <sub>2</sub> (g), OH <sup>-</sup>	-0.8280	-0.8360
H <sup>+</sup> / H <sub>2</sub>	-0.091	-0.378	H <sub>2</sub> (g) / H <sup>+</sup>	(-2.40) <sup>a</sup> (-1.48)	
H <sup>+</sup> / H (g)	-2.1067	0.5111	H <sub>2</sub> O (liq) / H (g), OH <sup>-</sup>	-2.9347	-0.3249
H <sub>2</sub> (g) / H <sup>+</sup>		(-2.40) <sup>a</sup> (-1.48)			
<b>Lithium<sup>6-8</sup></b>					
Li <sup>+</sup> , H <sub>2</sub> (g) / LiH (c)	-2.331	-1.285	LiOH (c) / Li (c), OH <sup>-</sup>	-2.920	-0.930
Li <sup>+</sup> / Li (c)	-3.040	-0.514	Li <sup>+</sup> / Li (c)	-3.040	-0.514
			LiOH / Li (c), OH <sup>-</sup>	-3.060	-0.59
<b>Sodium<sup>6-8</sup></b>					
Na <sup>+</sup> , H <sub>2</sub> (g) / NaH (c)	-2.367	-1.550	NaOH / Na (c), OH <sup>-</sup>	-2.704	-0.73
Na <sup>+</sup> / Na (c)	-2.7143	-0.757	Na <sup>+</sup> / Na (c)	-2.7143	-0.757
<b>Potassium<sup>6-8</sup></b>					
K <sup>+</sup> , H <sub>2</sub> (g) / KH (c)	(-2.58) <sup>b</sup> (-1.90)		KOH / K (c), OH <sup>-</sup>	-2.909	(-0.9)
K <sup>+</sup> / K (c)	-2.936	-1.074	K <sup>+</sup> / K (c)	-2.936	-1.074
<b>Rubidium<sup>6, 7</sup></b>					
Rb <sup>+</sup> , H <sub>2</sub> (g) / RbH (c)	(-2.66) <sup>b</sup> (-1.99)		RbOH / Rb (c), OH <sup>-</sup>	(-2.91)	
Rb <sup>+</sup> / Rb (c)	-2.943	-1.140	Rb <sup>+</sup> / Rb (c)	-2.943	-1.140
<b>Cesium<sup>6-8</sup></b>					
Cs <sup>+</sup> , H <sub>2</sub> (g) / CsH (c)	(-2.72) <sup>b</sup> (-2.04)		CsOH / Cs (c), OH <sup>-</sup>	(-2.97)	
Cs <sup>+</sup> / Cs (c)	-3.026	-1.172	Cs <sup>+</sup> / Cs (c)	-3.026	-1.172
<b>Francium<sup>6, 7</sup></b>					
Fr <sup>+</sup> , H <sub>2</sub> (g) / FrH (c)	(-2.73) (-2.1)		FrOH / Fr (c), OH <sup>-</sup>	(-2.8)	
Fr <sup>+</sup> / Fr (c)	(-2.9)	(-1.2)	Fr <sup>+</sup> / Fr (c)	(-2.9)	(-1.2)
<b>Beryllium<sup>6-8</sup></b>					
BeOH <sup>+</sup> , H <sup>+</sup> / Be (c)	-1.808 (0.3)		Be(OH) <sub>4</sub> <sup>2-</sup> / Be (c), OH <sup>-</sup>	-2.517	-0.751
Be <sub>3</sub> (OH) <sub>3</sub> <sup>5+</sup> , H <sup>+</sup> / Be (c)	-1.880		Be(OH) <sub>3</sub> <sup>5+</sup> / Be (c), OH <sup>-</sup>	-2.32	
Be <sup>2+</sup> / Be (c)	-1.968 (0.60)		Be(OH) <sub>2</sub> (pt) / Be (c), OH <sup>-</sup>	(-2.58) <sup>b</sup> (-1.05)	
Be <sup>2+</sup> , H <sub>2</sub> (g) / BeH <sub>2</sub> (c)	(-2.26) (-0.05)		Be(OH) <sub>2</sub> (c, a) / Be (c), OH <sup>-</sup>	-2.598	-1.022
			BeO (c) / Be (c), OH <sup>-</sup>	-2.606	-1.174
			Be(OH) <sub>2</sub> (c, b) / Be (c), OH <sup>-</sup>	-2.609	-1.001
<b>Magnesium<sup>6-8</sup></b>					
MgOH <sup>+</sup> , H <sup>+</sup> / Mg (c)	-2.022 (0.25)		MgO (c) / Mg (c), OH <sup>-</sup>	-2.550	-1.120
Mg <sub>4</sub> (OH) <sub>4</sub> <sup>4+</sup> , H <sup>+</sup> /	-2.067		Mg(OH) <sub>2</sub> (pt) / Mg (c), OH <sup>-</sup>	(-2.68) <sup>b</sup> (-0.98)	
Mg (c)			Mg(OH) <sub>2</sub> (c) / Mg (c), OH <sup>-</sup>	-2.690	-0.946
Mg <sup>2+</sup> , H <sub>2</sub> (g) / MgH <sub>2</sub> (c)	-2.173	-0.486			
Mg <sup>2+</sup> / Mg (c)	-2.360	0.199			
<b>Calcium<sup>6-8</sup></b>					
Ca <sup>2+</sup> , H <sub>2</sub> (g) / CaH <sub>2</sub> (c)	-2.105	-0.86	CaOH <sup>+</sup> / Ca (c), OH <sup>-</sup>	-2.902	-0.46
CaOH <sup>+</sup> , H <sup>+</sup> / Ca (c)	-2.488	-0.05	Ca(OH) <sub>2</sub> (c) / Ca (c), OH <sup>-</sup>	-3.022	-0.991
Ca <sup>2+</sup> / Ca (c)	-2.868	-0.186			

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Strontrium<sup>6-8</sup></b>					
Sr <sup>2+</sup> , H <sub>2</sub> (g) / SrH <sub>2</sub> (c)	(-2.16) <sup>b</sup> (-0.90)		SrOH <sup>+</sup> / Sr (c), OH <sup>-</sup>	-2.920	
SrOH <sup>+</sup> , H <sup>+</sup> / Sr (c)			Sr(OH) <sub>2</sub> · 8 H <sub>2</sub> O (c) /	(-3.03) <sup>b</sup> (0.36)	
Sr <sup>2+</sup> / Sr (c)	-2.899	-0.237	Sr (c), OH <sup>-</sup>		
<b>Barium<sup>6-8</sup></b>					
Ba <sup>2+</sup> , H <sub>2</sub> (g) / BaH <sub>2</sub> (c)	(-2.18) <sup>b</sup> (-1.06)		BaOH <sup>+</sup> / Ba (c), OH <sup>-</sup>	-2.921	
BaOH <sup>+</sup> , H <sup>+</sup> / Ba (c)	-2.507		Ba(OH) <sub>2</sub> · 8 H <sub>2</sub> O (c) /	-3.00	0.29
Ba <sup>2+</sup> / Ba (c)	-2.906	-0.401	Ba (c), OH <sup>-</sup>		
<b>Radium<sup>6, 7, 11-13</sup></b>					
Ra <sup>2+</sup> , H <sub>2</sub> (g) / RaH <sub>2</sub> (c)	(-2.19) (-1.09)		RaOH <sup>+</sup> / Ra (c), OH <sup>-</sup>	(-2.81)	
RaOH <sup>+</sup> , H <sup>+</sup> / Ra (c)	(-2.40)		Ra(OH) <sub>2</sub> · 8 H <sub>2</sub> O (c) /	(-2.89)	
Ra <sup>2+</sup> / Ra (c)	(-2.80) (-0.44)		Ra (c), OH <sup>-</sup>		
<b>Scandium<sup>6-8, 11, 12</sup></b>					
Sc <sup>3+</sup> , H <sub>2</sub> (g) / ScH <sub>3</sub> (c)	(-1.75) (-0.25)		Sc(OH) <sub>4</sub> <sup>-</sup> / Sc (c), OH <sup>-</sup>	-2.68 (-1.16)	
Sc <sup>2+</sup> / Sc (c)	(-2.0) <sup>a</sup> (-0.2)		Sc(OH) <sub>3</sub> (pt) / Sc (c), OH <sup>-</sup>	-2.69 -1.01	
ScOH <sup>2+</sup> , H <sup>+</sup> / Sc (c)	-2.01	0.24	Sc(OH) <sub>3</sub> (c) / Sc (c), OH <sup>-</sup>	-2.72 (-0.96)	
Sc <sub>2</sub> (OH) <sub>2</sub> <sup>4+</sup> , H <sup>+</sup> / Sc (c)	-2.03		Sc <sub>2</sub> O <sub>3</sub> (c, y) / Sc (c), OH <sup>-</sup>	-2.742 -1.164	
Sc <sup>3+</sup> / Sc (c)	-2.09	0.41	ScOOH (c) / Sc (c), OH <sup>-</sup>	(-2.76) (-1.10)	
Sc <sup>3+</sup> / Sc <sup>2+</sup>	(-2.3) <sup>a</sup> (1.6)				
<b>Yttrium<sup>6-9</sup></b>					
Y <sup>3+</sup> , H <sub>2</sub> (g) / YH <sub>3</sub> (c)	(-1.72) (-0.32)		Y(OH) <sub>3</sub> (pt) / Y (c), OH <sup>-</sup>	(-2.87)	
YOH <sup>2+</sup> , H <sup>+</sup> / Y (c)	-2.23 (0.2)		Y(OH) <sub>3</sub> (c) / Y (c), OH <sup>-</sup>	-2.90 -0.977	
Y <sup>3+</sup> / Y (c)	-2.38	0.34			
<b>Lanthanum<sup>1, 8, 9</sup></b>					
La <sup>3+</sup> , H <sub>2</sub> (g) / LaH <sub>3</sub> (c)	(-1.71) (-0.41)		La(OH) <sub>3</sub> (pt) / La (c), OH <sup>-</sup>	-2.75	
LaOH <sup>2+</sup> , H <sup>+</sup> / La (c)	-2.21 (0.1)		La(OH) <sub>3</sub> (c) / La (c), OH <sup>-</sup>	-2.80 -0.998	
La <sup>3+</sup> / La (c)	-2.379	0.242			
<b>Cerium<sup>6-9</sup></b>					
Ce <sup>4+</sup> / Ce <sup>3+</sup>	1.72	1.54	Ce <sub>4</sub> O <sub>7</sub> (c) / Ce(OH) <sub>3</sub> (c), OH <sup>-</sup>	(-0.13) (-2.03)	
CeOH <sup>3+</sup> , H <sup>+</sup> / Ce <sup>3+</sup>	1.68	-0.13	CeO <sub>2</sub> (pt) /	(-0.5)	
CeO <sub>2</sub> (pt), H <sup>+</sup> / Ce <sup>3+</sup>	(1.66) (-2.1)		Ce(OH) <sub>3</sub> (pt), OH <sup>-</sup>		
Ce <sub>2</sub> (OH) <sub>6</sub> <sup>4+</sup> , H <sup>+</sup> / Ce <sup>3+</sup>	(1.64)		CeO <sub>2</sub> (c) / Ce(OH) <sub>3</sub> (c), OH <sup>-</sup>	-0.70 (-1.54)	
CeO <sub>2</sub> (c), H <sup>+</sup> / Ce <sup>3+</sup>	1.304	-2.00	CeO <sub>2</sub> (c) / Ce <sub>4</sub> O <sub>7</sub> (c), OH <sup>-</sup>	(-1.27) (-1.04)	
CeO <sub>2</sub> (c), H <sup>+</sup> / CeOH <sup>2+</sup>	0.81		Ce(OH) <sub>3</sub> (pt) / Ce (c), OH <sup>-</sup>	(-2.73)	
CeOH <sup>2+</sup> , H <sup>+</sup> / Ce (c)	-2.17		Ce(OH) <sub>3</sub> (c) / Ce (c), OH <sup>-</sup>	-2.77 (-0.99)	
Ce <sup>3+</sup> / Ce (c)	-2.336	0.280			
<b>Praseodymium<sup>6-9, 11, 12</sup></b>					
Pr <sup>4+</sup> / Pr <sup>3+</sup>	(3.2)	(1.4)	Pr <sub>6</sub> O <sub>11</sub> (c) /	(0.94) <sup>b</sup> (-1.91)	
PrO <sub>2</sub> (pt), H <sup>+</sup> / Pr <sup>3+</sup>	(3.0)		Pr(OH) <sub>3</sub> (c), OH <sup>-</sup>		
PrO <sub>2</sub> (c), H <sup>+</sup> / Pr <sup>3+</sup>	(2.67) <sup>b</sup> (-2.17)		PrO <sub>2</sub> (pt) /	(0.9)	
PrO <sub>2</sub> (c), H <sup>+</sup> / PrOH <sup>2+</sup>	(2.18)		Pr(OH) <sub>3</sub> (pt), OH <sup>-</sup>		
Pr <sup>2+</sup> / Pr (c)	(-2.0) <sup>a</sup> (-0.4)		PrO <sub>2</sub> (c) / Pr(OH) <sub>3</sub> (c), OH <sup>-</sup>	(0.70) <sup>b</sup> (-1.67)	
PrOH <sup>2+</sup> , H <sup>+</sup> / Pr (c)	-2.19		PrO <sub>2</sub> (c) / Pr <sub>6</sub> O <sub>11</sub> (c), OH <sup>-</sup>	(0.22) <sup>b</sup> (-1.19)	
Pr <sup>3+</sup> / Pr (c)	-2.333	0.291	Pr(OH) <sub>3</sub> (pt) / Pr (c), OH <sup>-</sup>	(-2.76)	
Pr <sup>3+</sup> / Pr <sup>2+</sup>	(-3.1) <sup>a</sup> (1.6)		Pr(OH) <sub>3</sub> (c) / Pr (c), OH <sup>-</sup>	-2.80 -0.990	

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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**Neodymium<sup>6-9, 11, 12</sup>**

$\text{Nd}^{2+} / \text{Nd}(\text{c})$	(-2.1) <sup>a</sup> (-0.4)	$\text{Nd}(\text{OH})_3(\text{pt}) / \text{Nd}(\text{c}), \text{OH}^-$	(-2.74)		
$\text{NdOH}^{2+}, \text{H}^+ / \text{Nd}(\text{c})$	-2.16	$\text{Nd}(\text{OH})_3(\text{c}) / \text{Nd}(\text{c}), \text{OH}^-$	-2.78	-0.990	
$\text{Nd}^{3+} / \text{Nd}(\text{c})$	-2.323 0.282				
$\text{Nd}^{3+} / \text{Nd}^{2+}$	(-2.7) <sup>a</sup> (1.6)				

**Promethium<sup>9, 11, 12</sup>**

$\text{PmOH}^{2+}, \text{H}^+ / \text{Pm}(\text{c})$	(-2.14)	$\text{Pm}(\text{OH})_3(\text{pt}) / \text{Pm}(\text{c}), \text{OH}^-$	(-2.74)		
$\text{Pm}^{2+} / \text{Pm}(\text{c})$	(-2.2) <sup>a</sup> (-0.3)	$\text{Pm}(\text{OH})_3(\text{c}) / \text{Pm}(\text{c}), \text{OH}^-$	(-2.78)	(-0.99)	
$\text{Pm}^{3+} / \text{Pm}(\text{c})$	(-2.30) 0.29				
$\text{Pm}^{3+} / \text{Pm}^{2+}$	(-2.6) <sup>a</sup> (1.5)				

**Samarium<sup>6-9</sup>**

$\text{Sm}^{3+} / \text{Sm}^{2+}$	-1.35 (1.4)	$\text{Sm}(\text{OH})_3(\text{pt}) / \text{Sm}(\text{c}), \text{OH}^-$	(-2.75)		
$\text{SmOH}^{2+}, \text{H}^+ / \text{Sm}(\text{c})$	-2.15	$\text{Sm}(\text{OH})_2 \cdot \text{H}_2\text{O}(\text{c}) /$	(-2.77) <sup>a</sup> (-0.9)		
$\text{Sm}^{3+} / \text{Sm}(\text{c})$	-2.304 0.279	$\text{Sm}(\text{c}), \text{OH}^-$			
$\text{Sm}^{2+} / \text{Sm}(\text{c})$	-2.68 (-0.28)	$\text{Sm}(\text{OH})_3(\text{c}) / \text{Sm}(\text{c}), \text{OH}^-$	-2.78 (-0.98)		
		$\text{Sm}(\text{OH})_3(\text{c}) /$	(-2.8) <sup>a</sup> (-1.2)		
		$\text{Sm}(\text{OH})_2 \cdot \text{H}_2\text{O}(\text{c}), \text{OH}^-$			

**Europium<sup>6-9</sup>**

$\text{EuOH}^{2+}, \text{H}^+ / \text{Eu}^{2+}$	0.11	$\text{Eu}(\text{OH})_3(\text{c}) /$	(-1.6) (-1.1)		
$\text{Eu}^{3+} / \text{Eu}^{2+}$	-0.35 1.33	$\text{Eu}(\text{OH})_2 \cdot \text{H}_2\text{O}(\text{c}), \text{OH}^-$			
$\text{EuOH}^{2+}, \text{H}^+ / \text{Eu}(\text{c})$	-1.84	$\text{Eu}(\text{OH})_3(\text{pt}) / \text{Eu}(\text{c}), \text{OH}^-$	(-2.44)		
$\text{Eu}^{3+} / \text{Eu}(\text{c})$	-1.991 0.338	$\text{Eu}(\text{OH})_3(\text{c}) / \text{Eu}(\text{c}), \text{OH}^-$	-2.48 -0.934		
$\text{Eu}^{2+} / \text{Eu}(\text{c})$	-2.812 -0.26	$\text{Eu}(\text{OH})_2 \cdot \text{H}_2\text{O}(\text{c}) /$	(-2.92) (-0.85)		
		$\text{Eu}(\text{c}), \text{OH}^-$			

**Cerium<sup>6-9</sup>**

$\text{GdOH}^{2+}, \text{H}^+ / \text{Gd}(\text{c})$	-2.12	$\text{Gd}(\text{OH})_3(\text{pt}) / \text{Gd}(\text{c}), \text{OH}^-$	(-2.74)		
$\text{Gd}^{3+} / \text{Gd}(\text{c})$	-2.279 0.315	$\text{Gd}(\text{OH})_3(\text{c}) / \text{Gd}(\text{c}), \text{OH}^-$	-2.78 -0.990		

**Terbium<sup>6-9</sup>**

$\text{Tb}^{4+} / \text{Tb}^{3+}$	(3.1) (1.5)	$\text{Tb}_4\text{O}_7(\text{c}) / \text{Tb}(\text{OH})_3(\text{c}), \text{OH}^-$	(1.04) <sup>b</sup> (-2.27)		
$\text{TbO}_2(\text{pt}), \text{H}^+ / \text{Tb}^{3+}$	(2.7)	$\text{TbO}_2(\text{pt}) /$	(0.8)		
$\text{TbO}_2(\text{c}), \text{H}^+ / \text{Tb}^{3+}$	(2.44) <sup>b</sup> (-2.36)	$\text{Tb}(\text{OH})_3(\text{pt}), \text{OH}^-$			
$\text{TbO}_2(\text{c}), \text{H}^+ / \text{TbOH}^{2+}$	(1.97)	$\text{TbO}_2(\text{c}) / \text{Tb}(\text{OH})_3(\text{c}), \text{OH}^-$	(0.64) <sup>b</sup> (-1.72)		
$\text{TbOH}^{2+}, \text{H}^+ / \text{Tb}(\text{c})$	-2.12	$\text{TbO}_2(\text{c}) / \text{Tb}_4\text{O}_7(\text{c}), \text{OH}^-$	(0.24) <sup>b</sup> (-1.16)		
$\text{Tb}^{3+} / \text{Tb}(\text{c})$	-2.28 0.350	$\text{Tb}(\text{OH})_3(\text{pt}) / \text{Tb}(\text{c}), \text{OH}^-$	(-2.73)		
		$\text{Tb}(\text{OH})_3(\text{c}) / \text{Tb}(\text{c}), \text{OH}^-$	-2.78 -0.979		

**Dysprosium<sup>6-9, 11, 12</sup>**

$\text{DyOH}^{2+}, \text{H}^+ / \text{Dy}(\text{c})$	-2.14	$\text{Dy}(\text{OH})_3(\text{pt}) / \text{Dy}(\text{c}), \text{OH}^-$	(-2.77)		
$\text{Dy}^{2+} / \text{Dy}(\text{c})$	(-2.2) <sup>a</sup> (-0.3)	$\text{Dy}(\text{OH})_3(\text{c}) / \text{Dy}(\text{c}), \text{OH}^-$	-2.81 (-0.98)		
$\text{Dy}^{3+} / \text{Dy}(\text{c})$	-2.295 0.373				
$\text{Dy}^{3+} / \text{Dy}^{2+}$	(-2.6) <sup>a</sup> (1.6)				

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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**Holmium<sup>6-9, 11, 12</sup>**

$\text{Ho}^{2+} / \text{Ho}(\text{c})$	(-2.1) <sup>a</sup> (-0.2)	$\text{Ho}(\text{OH})_3(\text{pt}) / \text{Ho}(\text{c}), \text{OH}^-$	(-2.82)		
$\text{HoOH}^{2+}, \text{H}^+ / \text{Ho}(\text{c})$	-2.18	$\text{Ho}(\text{OH})_3(\text{c}) / \text{Ho}(\text{c}), \text{OH}^-$	-2.85 -0.977		
$\text{Ho}^{3+} / \text{Ho}(\text{c})$	-2.33 0.371				
$\text{Ho}^{3+} / \text{Ho}^{2+}$	(-2.8) <sup>a</sup> (1.6)				

**Erbium<sup>6-9, 11, 12</sup>**

$\text{Er}^{2+} / \text{Er}(\text{c})$	(-2.0) <sup>a</sup> (-0.2)	$\text{Er}(\text{OH})_3(\text{pt}) / \text{Er}(\text{c}), \text{OH}^-$	(-2.83)		
$\text{ErOH}^{2+}, \text{H}^+ / \text{Er}(\text{c})$	-2.18	$\text{Er}(\text{OH})_3(\text{c}) / \text{Er}(\text{c}), \text{OH}^-$	-2.86 (-0.98)		
$\text{Er}^{3+} / \text{Er}(\text{c})$	-2.331 0.388				
$\text{Er}^{3+} / \text{Er}^{2+}$	(-3.0) <sup>a</sup> (1.6)				

**Thulium<sup>6-9, 11, 12</sup>**

$\text{TmOH}^{2+}, \text{H}^+ / \text{Tm}(\text{c})$	-2.17	$\text{Tm}(\text{OH})_3(\text{pt}) / \text{Tm}(\text{c}), \text{OH}^-$	(-2.82)		
$\text{Tm}^{3+} / \text{Tm}^{2+}$	(-2.2) <sup>a</sup> (1.6)	$\text{Tm}(\text{OH})_3(\text{c}) / \text{Tm}(\text{c}), \text{OH}^-$	-2.85 (-0.97)		
$\text{Tm}^{3+} / \text{Tm}(\text{c})$	-2.319 0.394				
$\text{Tm}^{2+} / \text{Tm}(\text{c})$	(-2.4) <sup>a</sup> (-0.2)				

**Ytterbium<sup>6-9, 11, 12</sup>**

$\text{Yb}^{3+} / \text{Yb}^{2+}$	-1.05 (1.4)	$\text{Yb}(\text{OH})_3(\text{c}) /$	(-2.3) (-1.0)		
$\text{YbOH}^{2+}, \text{H}^+ / \text{Yb}(\text{c})$	-2.04	$\text{Yb}(\text{OH})_2(\text{c}), \text{OH}^-$			
$\text{Yb}^{3+} / \text{Yb}(\text{c})$	-2.19 0.363	$\text{Yb}(\text{OH})_3(\text{pt}) / \text{Yb}(\text{c}), \text{OH}^-$	(-2.70)		
$\text{Yb}^{2+} / \text{Yb}(\text{c})$	-2.76 (-0.16)	$\text{Yb}(\text{OH})_3(\text{c}) / \text{Yb}(\text{c}), \text{OH}^-$	-2.73 (-1.00)		
		$\text{Yb}(\text{OH})_2(\text{c}) / \text{Yb}(\text{c}), \text{OH}^-$	(-2.94) (-1.0)		

**Lutetium<sup>6-9, 11, 12</sup>**

$\text{LuOH}^{2+}, \text{H}^+ / \text{Lu}(\text{c})$	-2.13	$\text{Lu}(\text{OH})_3(\text{pt}) / \text{Lu}(\text{c}), \text{OH}^-$	(-2.79)		
$\text{Lu}^{3+} / \text{Lu}(\text{c})$	-2.28 0.412	$\text{Lu}(\text{OH})_3(\text{c}) / \text{Lu}(\text{c}), \text{OH}^-$	-2.82 (-0.97)		

**Actinium<sup>9, 11-13</sup>**

$\text{Ac}^{3+}, \text{H}_2(\text{g}) / \text{AcH}_3(\text{c})$	(-1.70) (-0.46)	$\text{Ac}(\text{OH})_3(\text{pt}) / \text{Ac}(\text{c}), \text{OH}^-$	(-2.53)		
$\text{Ac}^{3+} / \text{Ac}(\text{c})$	(-2.20) (0.19)	$\text{Ac}(\text{OH})_3(\text{c}) / \text{Ac}(\text{c}), \text{OH}^-$	(-2.57) (-1.01)		

**Thorium<sup>6-9</sup>**

$\text{Th}^{4+}, \text{H}_2(\text{g}) /$	-1.468 -0.075	$\text{ThO}_2(\text{pt}) / \text{Th}(\text{c}), \text{OH}^-$	-2.55 (-1.21)		
$\text{Th}_4\text{H}_{15}(\text{c})$		$\text{ThO}_2(\text{c}) / \text{Th}(\text{c}), \text{OH}^-$	-2.627 -1.181		
$\text{ThOH}^{3+}, \text{H}^+ / \text{Th}(\text{c})$	-1.779 0.31				
$\text{Th}_2(\text{OH})_2^{6+}, \text{H}^+ / \text{Th}(\text{c})$	-1.78				
$\text{Th}^{4+} / \text{Th}(\text{c})$	-1.826 0.557				

**Protactinium<sup>6-9, 11-13</sup>**

## STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

5

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Uranium <sup>6-9, 11-13</sup>					
$\text{UO}_2^+ / \text{UO}_2$ (c)	0.66	(0.3)	$\text{UO}_2\text{OH}$ (c) / $\text{UO}_2$ (c), $\text{OH}^-$	(0.1) <sup>a</sup>	
$\text{UO}_2\text{OH}^+, \text{H}^+ / \text{UO}_2$ (c)	0.58	0.00	$\text{UO}_2(\text{OH})_2^- / \text{UO}_2$ (pt), $\text{OH}^-$	(-0.1) <sup>a</sup>	
$(\text{UO}_2)_3(\text{OH})_5^+, \text{H}^+ /$ $\text{UO}_2$ (c)	0.564	0.16	$\text{UO}_2(\text{OH})_2$ (c, β) / $\text{U}_3\text{O}_8$ (c, α), $\text{OH}^-$	-0.139 -0.57	
$(\text{UO}_2)_2(\text{OH})_2^{2+}, \text{H}^+ /$ $\text{UO}_2$ (c)	0.493	0.16	$\text{UO}_2(\text{OH})_4^{2-} / \text{UO}_2$ (c), $\text{OH}^-$	(-0.22)	
$\text{UO}_2^+ / \text{UO}_2$ (c)	0.410	0.232	$\text{UO}_2$ (c), $\text{OH}^-$	-0.252 -1.05	
$\text{UO}_2^+, \text{H}^+ / \text{U}^{4+}$	0.39	(-3.4)	$\text{U}_3\text{O}_8$ (c, α) / $\text{UO}_2$ (c), $\text{OH}^-$	-0.309 -1.284	
$\text{UO}_2^{2+}, \text{H}^+ / \text{U}^{4+}$	0.273	-1.582	$\text{UO}_2(\text{OH})_4^{2-} / \text{UO}_2$ (pt), $\text{OH}^-$	(-0.43)	
$\text{UO}_2^{2+}, \text{H}^+ / \text{UOH}^{3+}$	0.254	-0.92	$\text{UO}_2(\text{OH})_4^{2-} /$	(-0.5) <sup>a</sup>	
$\text{UO}_2^{2+} / \text{UO}_2^+$	0.16	(0.2)	$\text{UO}_2\text{OH}$ (c), $\text{OH}^-$		
$\text{UOH}^{3+}, \text{H}^+ / \text{U}^{3+}$	-0.539	0.29	$\text{UO}_2(\text{OH})_2$ (c, β) /	(-0.6) <sup>a</sup>	
$\text{U}^{4+} / \text{U}^{3+}$	-0.577	1.61	$\text{UO}_2\text{OH}$ (c), $\text{OH}^-$		
$\text{UO}_2$ (c), $\text{H}^+ / \text{U}^{3+}$	-0.851	-2.02	$\text{UO}_2(\text{OH})_4^{2-} /$	(-0.7) <sup>a</sup>	
$\text{U}^{3+}, \text{H}_2$ (g) / $\text{UH}_3$ (c)	-1.390	-0.47	$\text{UO}_2(\text{OH})_2^- / \text{OH}^-$		
$\text{UO}_2$ (c), $\text{H}^+ / \text{U}$ (c)	-1.444	-0.384	$\text{U}(\text{OH})_3$ (pt) / $\text{U}$ (c), $\text{OH}^-$	(-2.04) <sup>a</sup>	
$\text{U}^{3+} / \text{U}$ (c)	-1.642	0.16	$\text{U}(\text{OH})_3$ (c) / $\text{U}$ (c), $\text{OH}^-$	(-2.08) <sup>a</sup> (-1.10)	
			$\text{UO}_2$ (pt) / $\text{U}$ (c), $\text{OH}^-$	(-2.16)	
			$\text{UO}_2$ (c) / $\text{U}$ (c), $\text{OH}^-$	-2.272 -1.220	
			$\text{UO}_2$ (pt) / $\text{U}(\text{OH})_3$ (pt), $\text{OH}^-$	(-2.6) <sup>a</sup>	
			$\text{UO}_2$ (c) / $\text{U}(\text{OH})_3$ (c), $\text{OH}^-$	(-2.9) <sup>a</sup> (-1.6)	

Neptunium <sup>8, 9, 11-13</sup>					
$\text{NpO}_3^+, \text{H}^+ / \text{NpO}_2^{2+}$	2.04		$\text{NpO}_4(\text{OH})_3^- /$	(0.61)	
$\text{NpO}_2\text{OH}^+, \text{H}^+ / \text{NpO}_2$	1.54		$\text{NpO}_2(\text{OH})_2$ (c), $\text{OH}^-$		
$(\text{NpO}_2)_2(\text{OH})_2^{2+}, \text{H}^+ /$ $\text{NpO}_2^+$	1.43		$\text{NpO}_4(\text{OH})_2^{3-} /$	0.58	
			$\text{NpO}_2(\text{OH})_4^{2-}, \text{OH}^-$		
$\text{NpO}_2^{2+} / \text{NpO}_2^+$	1.236	0.058	$\text{NpO}_2(\text{OH})_4^{2-} /$	(0.5)	
$\text{NpO}_2^+ / \text{NpO}_2$ (c)	1.092	0.33	$\text{NpO}_2\text{OH}$ (c), $\text{OH}^-$		
$\text{NpO}_2^+, \text{H}^+ / \text{Np}^{4+}$	0.567	-3.30	$\text{NpO}_2(\text{OH})_2$ (c) /	(0.5) (-1.1)	
$\text{NpO}_2^+, \text{H}^+ / \text{NpOH}^{3+}$	0.479		$\text{NpO}_2\text{OH}$ (c), $\text{OH}^-$		
$\text{NpOH}^{3+}, \text{H}^+ / \text{Np}^{3+}$	0.245		$\text{NpO}_2(\text{OH})_4^{2-} /$	(0.49)	
$\text{Np}^{4+} / \text{Np}^{3+}$	0.157	1.53	$\text{NpO}_2$ (c), $\text{OH}^-$		
$\text{NpO}_2$ (c), $\text{H}^+ / \text{Np}^{3+}$	-0.369	-2.10	$\text{NpO}_2(\text{OH})_2$ (c) /	(0.48) <sup>b</sup> (-1.10)	
$\text{NpO}_2$ (c), $\text{H}^+ / \text{Np}$ (c)	-1.418	-0.392	$\text{NpO}_2$ (c), $\text{OH}^-$		
$\text{Np}^{3+} / \text{Np}$ (c)	-1.768	0.18	$\text{NpO}_2\text{OH}$ (c) / $\text{NpO}_2$ (c), $\text{OH}^-$	(0.4) (-1.1)	
			$\text{NpO}_2(\text{OH})_4^{2-} /$	(0.4) <sup>a</sup>	
			$\text{NpO}_2(\text{OH})_2^- / \text{OH}^-$		
			$\text{NpO}_2(\text{OH})_4^{2-} /$	(0.22)	
			$\text{NpO}_2$ (pt), $\text{OH}^-$		
			$\text{NpO}_2(\text{OH})_2^- /$	(0.1) <sup>a</sup>	
			$\text{NpO}_2$ (pt), $\text{OH}^-$		
			$\text{NpO}_2$ (pt) /	(-1.9)	
			$\text{Np}(\text{OH})_3$ (pt), $\text{OH}^-$		
			$\text{NpO}_2$ (pt) / $\text{Np}$ (c), $\text{OH}^-$	(-2.11)	
			$\text{Np}(\text{OH})_3$ (pt) / $\text{Np}$ (c), $\text{OH}^-$	(-2.18)	
			$\text{Np}(\text{OH})_3$ (c) / $\text{Np}$ (c), $\text{OH}^-$	-2.22 (-1.09)	
			$\text{NpO}_2$ (c) / $\text{Np}$ (c), $\text{OH}^-$	-2.246 -1.228	
			$\text{NpO}_2$ (c) / $\text{Np}(\text{OH})_3$ (c), $\text{OH}^-$	-2.33 (-1.6)	

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
$\text{PuO}_4^+, \text{H}^+ / \text{PuO}_2^{2+}$	(2.4)		$\text{PuO}_4(\text{OH})_3^{3-} /$	0.95	
$\text{PuO}_2^+ / \text{PuO}_2$ (c)	1.585	0.39	$\text{PuO}_2(\text{OH})_4^{2-}, \text{OH}^-$		
$\text{PuO}_2\text{OH}^+, \text{H}^+ / \text{PuO}_2$ (c)	1.44		$\text{PuO}_2\text{OH}$ (c) / $\text{PuO}_2$ (c), $\text{OH}^-$	(0.9)	
$(\text{PuO}_2)_2(\text{OH})_2^{2+}, \text{H}^+ /$	1.40		$\text{PuO}_2(\text{OH})_4^{2-} / \text{PuO}_2$ (c), $\text{OH}^-$	(0.57)	
$\text{PuO}_2$ (c)			$\text{PuO}_2(\text{OH})_2^- / \text{PuO}_2$ (c), $\text{OH}^-$	(0.5) <sup>a</sup>	
$\text{PuO}_2\text{OH}^+, \text{H}^+ / \text{PuO}_2^+$	1.29		$\text{PuO}_2(\text{OH})_4^{2-} /$	(0.3)	
$\text{PuO}_2^{2+} / \text{PuO}_2$ (c)	1.275	0.21	$\text{PuO}_2\text{OH}$ (c), $\text{OH}^-$		
$(\text{PuO}_2)_2(\text{OH})_2^{2+}, \text{H}^+ /$	1.21		$\text{PuO}_2(\text{OH})_4^{2-} /$	(0.29)	
$\text{PuO}_2^+$			$\text{PuO}_2$ (pt), $\text{OH}^-$		
$\text{PuO}_2\text{OH}^+, \text{H}^+ / \text{Pu}^{3+}$	1.036		$\text{Pu}(\text{OH})_3$ (pt), $\text{OH}^-$		
$\text{PuO}_2^+, \text{H}^+ / \text{Pu}^{4+}$	1.035	-3.26	$\text{PuO}_2$ (c) / $\text{Pu}(\text{OH})_3$ (c), $\text{OH}^-$	-1.47 (-1.7)	
$\text{PuO}_2^+, \text{H}^+ / \text{Pu}^{3+}$	1.021	-0.91	$\text{PuO}_2$ (pt) / $\text{Pu}$ (c), $\text{OH}^-$	(-2.06)	
$\text{Pu}^{4+} / \text{Pu}^{3+}$	1.006	1.441	$\text{PuO}_2$ (c) / $\text{Pu}$ (c), $\text{OH}^-$	-2.197 -1.22	
$\text{PuO}_2^+, \text{H}^+ / \text{PuOH}^{3+}$	1.005		$\text{Pu}(\text{OH})_3$ (pt) / $\text{Pu}$ (c), $\text{OH}^-$	(-2.40)	
$\text{PuO}_2^{2+}, \text{H}^+ / \text{Pu}^{3+}$	1.002	-0.596	$\text{Pu}(\text{OH})_3$ (c) / $\text{Pu}$ (c), $\text{OH}^-$	-2.44 (-1.05)	
$\text{PuO}_2^{2+}, \text{H}^+ / \text{Pu}^{4+}$	1.000	-1.615			
$\text{PuO}_2^{2+}, \text{H}^+ / \text{PuOH}^{3+}$	0.985				
$\text{PuO}_2^{2+} / \text{PuO}_2^+$	0.966	0.03			
$\text{PuO}_2$ (c), $\text{H}^+ / \text{Pu}^{3+}$	0.457	-2.20			
$\text{PuO}_2$ (c), $\text{H}^+ / \text{Pu}$ (c)	-1.369	-0.38			
$\text{Pu}^{2+} / \text{Pu}$ (c)	(-1.6) <sup>a</sup> (-0.4)				
$\text{Pu}^{3+} / \text{Pu}$ (c)	-1.978	0.23			
$\text{Pu}^{3+} / \text{Pu}^{2+}$	(-2.8) <sup>a</sup> (1.5)				
Americium <sup>9, 11-13</sup>					
$\text{AmO}_3^+, \text{H}^+ / \text{AmO}_2^{2+}$	(2.8)		$\text{AmO}_4(\text{OH})_3^{3-} /$	(1.3)	
$\text{Am}^{4+} / \text{Am}^{3+}$	(2.60)	(1.4)	$\text{AmO}_2(\text{OH})_4^{2-}, \text{OH}^-$		
$\text{AmO}_2$ (pt), $\text{H}^+ / \text{Am}^{3+}$	(2.56)		$\text{AmO}_2(\text{OH})_4^{2-} /$	(0.9)	
$\text{AmO}_2$ (c), $\text{H}^+ / \text{Am}^{3+}$	(1.95) <sup>b</sup> (-2.4)		$\text{AmO}_2\text{OH}$ (c), $\text{OH}^-$		
$\text{AmO}_2^+, \text{H}^+ / \text{Am}^{3+}$	1.698	-0.97	$\text{AmO}_2(\text{OH})_4^{2-} /$	(0.7) <sup>a</sup>	
$\text{AmO}_2^{2+}, \text{H}^+ / \text{Am}^{3+}$	1.662	-0.64	$\text{AmO}_2(\text{OH})_2^- / \text{OH}^-$		
$\text{AmO}_2^{2+} / \text{AmO}_2^+$	1.589	0.01	$\text{AmO}_2\text{OH}$ (c) / $\text{AmO}_2$ (c), $\text{OH}^-$	(0.7)	
$\text{AmO}_2^+ / \text{AmO}_2$ (c)	(1.44) <sup>b</sup> (0.4)		$\text{AmO}_2(\text{OH})_4^{2-} /$	(0.54)	
$\text{AmO}_2^+ / \text{AmO}_2$ (pt)	(0.84)		$\text{Am}(\text{OH})_3$ (c), $\text{OH}^-$		
$\text{AmO}_2^+, \text{H}^+ / \text{Am}^{4+}$	(0.80) (-3.3)		$\text{AmO}_2$ (pt) /	(0.5)	
$\text{Am}^{2+} / \text{Am}$ (c)	(-1.9) <sup>a</sup> (-0.5)		$\text{Am}(\text{OH})_3$ (pt), $\text{OH}^-$		
$\text{Am}^{3+} / \text{Am}$ (c)	-2.048	0.28	$\text{AmO}_2(\text{OH})_2^- /$	(0.50)	
$\text{Am}^{3+} / \text{Am}^{2+}$	(-2.3) <sup>a</sup> (1.8)		$\text{Am}(\text{OH})_3$ (pt), $\text{OH}^-$		
$\text{AmO}_2(\text{OH})_2^- /$			$\text{AmO}_2(\text{OH})_2^- /$	(0.4) <sup>a</sup>	
			$\text{Am}(\text{OH})_3$ (pt), $\text{OH}^-$		
			$\text{AmO}_2(\text{OH})_2^- /$	(0.2) <sup>a</sup>	
			$\text{AmO}_2$ (pt), $\text{OH}^-$		
			$\text{AmO}_2$ (c) /	(0.06) (-1.8)	
			$\text{Am}(\text{OH})_3$ (c), $\text{OH}^-$		
			$\text{Am}(\text{OH})_3$ (pt) / $\text{Am}$ (c), $\text{OH}^-$	(-2.48)	
			$\text{Am}(\text{OH})_3$ (c) / $\text{Am}$ (c), $\text{OH}^-$	-2.52 (-1.01)	

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Curium <sup>a</sup> , 11-13					
Cm <sup>4+</sup> / Cm <sup>3+</sup>	(3.0)	(1.7)	CmO <sub>2</sub> (pt) /	(0.9)	
CmO <sub>2</sub> (pt), H <sup>+</sup> / Cm <sup>3+</sup>	(2.9)		Cm(OH) <sub>3</sub> (pt), OH <sup>-</sup>		
CmO <sub>2</sub> (c), H <sup>+</sup> / Cm <sup>3+</sup>	(2.3) <sup>b</sup>	(-2.1)	CmO <sub>2</sub> (c) / Cm(OH) <sub>3</sub> (c), OH <sup>-</sup>	(0.4)	(-1.5)
Cm <sup>3+</sup> / Cm (c)	-2.04	0.29	Cm(OH) <sub>3</sub> (pt) / Cm (c), OH <sup>-</sup>	(-2.48)	
			Cm(OH) <sub>3</sub> (c) / Cm (c), OH <sup>-</sup>	-2.52	(-1.00)

Berkelium <sup>a</sup> , 11-13					
Bk <sup>4+</sup> / Bk <sup>3+</sup>	1.67	(1.6)	BkO <sub>2</sub> (pt) /	(-0.4)	
BkO <sub>2</sub> (pt), H <sup>+</sup> / Bk <sup>3+</sup>	(1.5)		Bk(OH) <sub>3</sub> (pt), OH <sup>-</sup>		
BkO <sub>2</sub> (c), H <sup>+</sup> / Bk <sup>3+</sup>	(0.9)	(-2.2)	BkO <sub>2</sub> (c) / Bk(OH) <sub>3</sub> (c), OH <sup>-</sup>	(-0.9)	(-1.7)
Bk <sup>2+</sup> / Bk (c)	(-1.6) <sup>b</sup>	(-0.3)	Bk(OH) <sub>3</sub> (pt) / Bk (c), OH <sup>-</sup>	(-2.43)	
Bk <sup>3+</sup> / Bk (c)	-1.98	0.32	Bk(OH) <sub>3</sub> (c) / Bk (c), OH <sup>-</sup>	-2.47	(-0.99)
Bk <sup>3+</sup> / Bk <sup>2+</sup>	(-2.8) <sup>b</sup>	(1.6)			

Californium <sup>a</sup> , 11-13					
Cf <sup>4+</sup> / Cf <sup>3+</sup>	(3.3)	(1.6)	CfO <sub>2</sub> (pt) / Cf(OH) <sub>3</sub> (pt), OH <sup>-</sup>	(1.2)	
CfO <sub>2</sub> (pt), H <sup>+</sup> / Cf <sup>3+</sup>	(3.1)		CfO <sub>2</sub> (c) / Cf(OH) <sub>3</sub> (c), OH <sup>-</sup>	(0.7)	(-1.7)
CfO <sub>2</sub> (c), H <sup>+</sup> / Cf <sup>3+</sup>	(2.5)	(-2.3)	Cf(OH) <sub>2</sub> (c) / Cf (c), OH <sup>-</sup>	(-2.2) <sup>b</sup>	(-1.0)
Cf <sup>3+</sup> / Cf <sup>2+</sup>	-1.6	(1.6)	Cf(OH) <sub>3</sub> (pt) / Cf (c), OH <sup>-</sup>	(-2.40)	
Cf <sup>3+</sup> / Cf (c)	-1.94	0.33	Cf(OH) <sub>3</sub> (c) / Cf (c), OH <sup>-</sup>	-2.44	(-0.99)
Cf <sup>2+</sup> / Cf (c)	-2.12	(-0.3)	Cf(OH) <sub>3</sub> (c) /	(-2.9) <sup>b</sup>	(-0.9)
			Cf(OH) <sub>2</sub> (c), OH <sup>-</sup>		

Einsteinium <sup>a</sup> , 11-13					
Es <sup>3+</sup> / Es <sup>2+</sup>	-1.3	(1.6)	Es(OH) <sub>2</sub> (c) / Es (c), OH <sup>-</sup>	(-2.3) <sup>b</sup>	(-1.0)
Es <sup>3+</sup> / Es (c)	(-1.91)	(0.37)	Es(OH) <sub>3</sub> (pt) / Es (c), OH <sup>-</sup>	(-2.38)	
Es <sup>2+</sup> / Es (c)	(-2.23)	(-0.3)	Es(OH) <sub>3</sub> (c) / Es (c), OH <sup>-</sup>	(-2.42)	(-0.95)
			Es(OH) <sub>3</sub> (c) /	(-2.6) <sup>b</sup>	(-0.9)
			Es(OH) <sub>2</sub> (c), OH <sup>-</sup>		

Fermium <sup>a</sup> , 11-13					
Fm <sup>3+</sup> / Fm <sup>2+</sup>	-1.1	(1.6)	Fm(OH) <sub>3</sub> (pt) / Fm (c), OH <sup>-</sup>	(-2.37)	
Fm <sup>3+</sup> / Fm (c)	(-1.89)	(0.38)	Fm(OH) <sub>3</sub> (c) /	(-2.4)	(-0.9)
Fm <sup>2+</sup> / Fm (c)	(-2.30)	(-0.3)	Fm(OH) <sub>2</sub> (c), OH <sup>-</sup>		
			Fm(OH) <sub>3</sub> (c) / Fm (c), OH <sup>-</sup>	(-2.40)	(-0.95)
			Fm(OH) <sub>2</sub> (c) / Fm (c), OH <sup>-</sup>	(-2.4)	(-1.0)

Mendelevium <sup>a</sup> , 11-13					
Md <sup>3+</sup> / Md <sup>2+</sup>	-0.1	(1.6)	Md(OH) <sub>3</sub> (c) /	(-1.4)	(-0.9)
Md <sup>3+</sup> / Md (c)	(-1.65)	(0.38)	Md(OH) <sub>2</sub> (c), OH <sup>-</sup>		
Md <sup>2+</sup> / Md (c)	(-2.40)	(-0.2)	Md(OH) <sub>3</sub> (pt) /	(-2.13)	
			Md (c), OH <sup>-</sup>		
			Md(OH) <sub>3</sub> (c) / Md (c), OH <sup>-</sup>	(-2.17)	(-0.96)
			Md(OH) <sub>2</sub> (c) / Md (c), OH <sup>-</sup>	(-2.5)	(-1.0)

Nobelium <sup>a</sup> , 11-13					
No <sup>3+</sup> / No <sup>2+</sup>	1.4	(1.5)	No(OH) <sub>3</sub> (c) /	(0.1)	(-1.0)
No <sup>3+</sup> / No (c)	(-1.20)	(0.34)	No(OH) <sub>2</sub> (c), OH <sup>-</sup>		
No <sup>2+</sup> / No (c)	(-2.50)	(-0.2)	No(OH) <sub>3</sub> (pt) / No (c), OH <sup>-</sup>	(-1.69)	
			No(OH) <sub>3</sub> (c) / No (c), OH <sup>-</sup>	(-1.72)	(-1.01)
			No(OH) <sub>2</sub> (c) / No (c), OH <sup>-</sup>	(-2.6)	(-1.0)

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Lawrencium <sup>a</sup> , 11-13					
Lr <sup>3+</sup> / Lr (c)	(-1.96)	(0.37)	Lr(OH) <sub>3</sub> (pt) / Lr (c), OH <sup>-</sup>	(-2.46)	
			Lr(OH) <sub>3</sub> (c) / Lr (c), OH <sup>-</sup>	(-2.49)	(-0.98)

Titanium <sup>a</sup> , 6-8					
Ti(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Ti <sup>3+</sup>	0.1	(0.6)	TiO <sub>2</sub> (OH) <sub>2</sub> <sup>2-</sup> /		(-1.2)
TiO <sub>2</sub> (pt), H <sup>+</sup> / Ti <sup>3+</sup>	0.1	(-2.7)	TiOOH (c), OH <sup>-</sup>		
TiO <sub>2</sub> (c, rutile), H <sup>+</sup> /	-0.2	(-2.7)	Ti <sub>3</sub> O <sub>5</sub> (c, a) / TiOOH (c), OH <sup>-</sup>	(-1.3)	(-1.9)
Ti <sup>3+</sup>			Ti <sub>3</sub> O <sub>5</sub> (c, a) / Ti <sub>2</sub> O <sub>3</sub> (c), OH <sup>-</sup>	-1.320	-1.267
Ti <sup>3+</sup> / Ti <sup>2+</sup>	(-0.9)	(1.0)	TiO <sub>2</sub> (c, rutile) /		-1.360
Ti(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Ti (c)	-1.00	0.14	Ti <sub>2</sub> O <sub>3</sub> (c), OH <sup>-</sup>		
TiO <sub>2</sub> (pt), H <sup>+</sup> / Ti (c)	-1.01	-0.37	TiO <sub>2</sub> (c, rutile) /		(-1.4)
TiO <sub>2</sub> (c, rutile), H <sup>+</sup> /	1.076	0.365	TiOOH (c), OH <sup>-</sup>		
Ti (c)			TiO <sub>2</sub> (c, rutile) /		-1.418
Ti <sup>3+</sup> / Ti (c)	-1.37	(0.40)	Ti <sub>3</sub> O <sub>5</sub> (c, a), OH <sup>-</sup>		
Ti <sup>2+</sup> / Ti (c)	(-1.60)	(-0.16)	TiO <sub>2</sub> (OH) <sub>2</sub> <sup>2-</sup> /		(-1.5)
			Ti(OH) <sub>3</sub> (pt), OH <sup>-</sup>		
			Ti(OH) <sub>2</sub> (pt), OH <sup>-</sup>		
			TiO <sub>2</sub> (OH) <sub>2</sub> <sup>2-</sup> / Ti (c), OH <sup>-</sup>		(-1.87)
			Ti <sub>2</sub> O <sub>3</sub> (c) / TiO (c, a), OH <sup>-</sup>		-1.901
			TiO <sub>2</sub> (c, rutile) / Ti (c), OH <sup>-</sup>		-1.904
			TiOOH (c) / Ti (c), OH <sup>-</sup>		(-2.0)
			Ti(OH) <sub>4</sub> <sup>-</sup> / Ti (c), OH <sup>-</sup>		(-2.0)
			Ti(OH) <sub>3</sub> (pt) / Ti (c), OH <sup>-</sup>		(-2.00)
			Ti <sub>2</sub> O <sub>3</sub> (c) / Ti (c), OH <sup>-</sup>		-2.076
			TiOOH (c) / Ti (c), OH <sup>-</sup>		(-2.08)
			Ti(OH) <sub>2</sub> (pt) / Ti (c), OH <sup>-</sup>		(-2.10)
			Ti(OH) <sub>2</sub> (c) / Ti (c), OH <sup>-</sup>		(-2.13)
			TiO (c, a) / Ti (c), OH <sup>-</sup>		-2.164
			TiO (c, a) / Ti (c), OH <sup>-</sup>		-1.125

Zirconium <sup>a</sup> , 6-8					
Zr <sup>4+</sup> / Zr (c)	-1.45	(0.67)	Zr <sub>3</sub> O <sub>5</sub> <sup>-</sup> / Zr (c), OH <sup>-</sup>	-2.22	
ZrOH <sup>3+</sup> , H <sup>+</sup> / Zr (c)	-1.45		ZrO <sub>2</sub> (pt) / Zr (c), OH <sup>-</sup>	-2.28	-1.19
Zr <sub>4</sub> O <sub>8</sub> <sup>8+</sup> , H <sup>+</sup> / Zr (c)	-1.47		ZrO <sub>2</sub> (c, a) / Zr (c), OH <sup>-</sup>	-2.301	-1.180
ZrO <sub>2</sub> (c, a), H <sup>+</sup> / Zr (c)	-1.473	-0.344			
Hafnium <sup>b</sup> , 5-8					
HfO <sub>3</sub> H <sup>3+</sup> , H <sup>+</sup> / Hf (c)	(-1.55)		Hf(OH) <sub>5</sub> <sup>-</sup> / Hf (c), OH <sup>-</sup>	-2.31	
Hf <sup>4+</sup> / Hf (c)	-1.55	(0.68)	HfO <sub>2</sub> (pt) / Hf (c), OH <sup>-</sup>	-2.37	-1.20
Hf <sub>4</sub> O <sub>8</sub> <sup>8+</sup> , H <sup>+</sup> / Hf (c)	(-1.57)		HfO <sub>2</sub> (c) / Hf (c), OH <sup>-</sup>	-2.419	-1.191
HfO <sub>2</sub> (c), H <sup>+</sup> / Hf (c)	-1.591	-0.355			

# STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

7

**Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K - Continued**

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Vanadium<sup>6, 7, 9</sup></b>					
$V_2O_4^{2+}, H^+ / VO^{2+}$	1.001	-0.901	$V_2O_2(c, \alpha) / V_3O_5(c, \alpha), OH^-$	-0.50	-1.10
$V_2O_2(OH)(pt), H^+ / VO^{2+}$	0.96	-1.51	$V_2O_2(c, \alpha) / V_2O_3(c, \alpha), OH^-$	-0.527	-1.172
$V_2O_3(c, \alpha), H^+ / VO^{2+}$	0.957	-1.656	$V_3O_5(c) / V_2O_3(c, \alpha), OH^-$	-0.57	-1.31
$VO^{2+}, H^+ / V^{3+}$	0.337 (-1.6)		$VO_2(OH)_2^{2-} / V_2O_3(c, \alpha), OH^-$	(-0.6)	
$VO_2^{+}, H^+ / V(c)$	-0.233	-0.239	$VO_2(OH)_2^{2-} / V_3O_5(c, \alpha), OH^-$	(-0.6)	
$VO_2OH(pt), H^+ / V(c)$	-0.24	-0.36	$VO_2(OH)_2^{2-} / VOOH(c, \alpha), OH^-$	(-0.6)	
$V_2O_5(c, \alpha), H^+ / V(c)$	-0.242	-0.390	$V_3O_5(c) / VOOH(c, \alpha), OH^-$	(-0.7)	(-2.0)
$V^{3+} / V^{2+}$	-0.255 (1.5)		$VO_4^{3-} / V_2O_3(c, \alpha), OH^-$	-0.704 (-0.72)	
$V^{2+} / V(c)$	-1.125 (-0.11)		$VO_4^{3-} / VOOH(c, \alpha), OH^-$	(-0.72)	(-0.8)
			$VO_4^{3-} / VO_2(OH)_2^{2-}, OH^-$	(-0.8)	
			$VO_4^{3-} / VO_2(c, \alpha), OH^-$	-0.882 (-0.27)	
			$VO_2(OH)_2^{2-} /$	(-0.9)	
			$V(OH)_3(pt), OH^-$		
			$VO_2(OH)_2^{2-} / V(OH)_4^-, OH^-$	(-1.0)	
			$V(OH)_4^-, V(OH)_2(c, \alpha), OH^-$	(-1.0)	
			$V(OH)_4^-, V(OH)_2(pt), OH^-$	(-1.0)	
			$V(OH)_3(pt) /$	(-1.2)	
			$VO(OH)_2(pt), OH^-$		
			$VO_4^{3-} / V(c), OH^-$	-1.222 (-1.02)	
			$VOOH(c) / V(OH)_2(c, \alpha), OH^-$	(-1.3)	(-1.3)
			$V_2O_3(c) / VO(c), OH^-$	-1.314	-1.256
			$VO(OH)_2(pt) / V(c), OH^-$	(-1.63)	
			$VO(OH)_2(c) / V(c), OH^-$	(-1.66)	(-1.05)
			$VO(c) / V(c), OH^-$	-1.693	-1.202
<b>Niobium<sup>6-8</sup></b>					
$Nb(OH)_2^{2+}, H^+ / Nb^{3+}$	(-0.1)		$Nb_6O_19^{8-} / NbO_2(c), OH^-$	(-1.34)	
$Nb(OH)_4^+, H^+ / Nb^{3+}$	(-0.2)		$Nb(OH)_3(pt) / Nb(c), OH^-$	(-1.4)	
$NbO_2(pt), H^+ / Nb^{3+}$	(-0.2)		$NbO_2(pt) / Nb(c), OH^-$	(-1.47)	
$Nb(OH)_4^+, H^+ /$	(-0.2)		$NbO_2(c) / NbO(c), OH^-$	-1.474	-1.183
$Nb(OH)_2^{2+}$			$Nb_6O_19^{8-} / Nb(c), OH^-$	(-1.48)	
$Nb_2O_5(c), H^+ /$	-0.248	-0.460	$Nb_6O_19^{8-} / NbO_2(pt), OH^-$	(-1.5)	
$NbO_2(c)$			$NbO_2(c) / Nb(c), OH^-$	-1.518	-1.197
$NbO_2OH(pt), H^+ /$	(-0.3)		$NbO(c) / Nb(c), OH^-$	-1.561	-1.211
$Nb^{3+}$			$NbO_2(pt) /$	(-1.6)	
$NbO_2(c), H^+ / Nb^{3+}$	(-0.4)		$Nb(OH)_3(pt), OH^-$		
$NbO_2OH(pt), H^+ /$	(-0.5)				
$NbO_2(pt)$					
$Nb(OH)_4^+, H^+ / Nb(c)$	-0.537				
$NbO_2OH(pt), H^+ /$	(-0.60)	(-0.35)			
$Nb(c)$					
$Nb_2O_5(c), H^+ / Nb(c)$	-0.601	-0.381			
$Nb(OH)_2^{2+}, H^+ / Nb(c)$	(-0.62)				
$NbO_2(pt), H^+ / Nb(c)$	(-0.64)				
$NbO_2(c), H^+ / NbO(c)$	-0.646	-0.347			
$NbO_2(c), H^+ / Nb(c)$	-0.690	-0.361			
$NbO(c), H^+ / Nb(c)$	-0.733	-0.375			
$Nb^{3+} / Nb(c)$	(-0.8)				
$Nb^{3+} / NbO(c), H^+$	(-0.9)				

**Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K - Continued**

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Tantalum<sup>6-8</sup></b>					
$Ta^{3+} / Ta(c)$	(-0.6) <sup>a</sup>		$Ta(OH)_3(pt) / Ta(c), OH^-$	(-1.3) <sup>a</sup>	
$Ta(OH)_2^{2+}, H^+ / Ta(c)$	(-0.64)		$TaO_2(pt) / Ta(c), OH^-$	(-1.30)	
$TaO_2(pt), H^+ / Ta(c)$	(-0.67)		$TaO_2(c) / Ta(c), OH^-$	(-1.36) (-1.19)	
$Ta(OH)_2^{2+}, H^+ / Ta^{3+}$	(-0.7) <sup>a</sup>		$Ta_6O_19^{8-} / Ta(c), OH^-$	(-1.60)	
$Ta(OH)_4^-, H^+ / Ta(c)$	-0.702		$Ta_6O_19^{8-} / TaO_2(c), OH^-$	(-1.8)	
$TaO_2(c), H^+ / Ta(c)$	(-0.73) (-0.36)		$Ta_6O_19^{8-} / TaO_2(pt), OH^-$	(-2.0)	
$TaO_2OH(pt), H^+ / Ta(c)$	(-0.75) (-0.35)		$TaO_2(pt) /$		(-2.1) <sup>a</sup>
$Ta_2O_5(c, \beta), H^+ / Ta(c)$	-0.752	-0.377	$Ta(OH)_3(pt), OH^-$		
$TaO_2(pt), H^+ / Ta^{3+}$	(-0.8) <sup>a</sup>				
$Ta_2O_5(c, \beta), H^+ /$	(-0.8) (-0.45)				
$TaO_2(c)$					
$Ta(OH)_4^-, H^+ /$	(-1.0)				
$Ta(OH)_2^{2+}$					
$TaO_2(c), H^+ / Ta^{3+}$	(-1.1) <sup>a</sup>				
$Ta_2O_7(pt), H^+ /$	(-1.1)				
$TaO_2(c)$					
$Cr(OH)_2^{2+}, H^+ / Cr^{3+}$	(1.8)		$CrO_2(c) / CrOOH(c), OH^-$	(0.25) <sup>b</sup> (-1.5)	
$CrO_2(pt), H^+ / Cr^{3+}$	(1.7)		$CrO_2(c) / Cr_2O_3(c, \alpha), OH^-$	(0.24) <sup>b</sup> (-1.3)	
$CrO_2(c), H^+ / Cr^{3+}$	(1.48) <sup>b</sup> (-2.9)		$CrO_2(pt) /$	(0.2)	
$HCrO_4^-, H^+ / Cr^{3+}$	1.37	-1.38	$Cr(OH)_3(pt, aged), OH^-$		
$Cr_2O_7^{2-}, H^+ / Cr^{3+}$	1.36	-1.32	$CrO_2(pt) /$	(0.1)	
$HCrO_4^-, H^+ / Cr_2(OH)_2^{4+}$	1.31		$Cr(OH)_3(pt, fresh), OH^-$		
$Cr_2O_5(c), H^+ / CrO_2(c)$	(1.3) (-0.4)		$Cr(OH)_6^{2-} / Cr(OH)_4^-, OH^-$	(0.1)	
$Cr_2O_7^{2-}, H^+ / Cr_2(OH)_2^{4+}$	1.30		$CrO_4^{2-} / CrO_3^{3-}$	0.1	
$Cr_2O_7^{2-}, H^+ / CrO_2(c)$	(1.30) <sup>b</sup> (-0.54)		$CrO_4^{2-} / CrOOH(c), OH^-$	(-0.01) <sup>b</sup> (-1.37)	
$H_3CrO_4, H^+ / CrO_2(pt)$	(1.3)		$CrO_4^{2-} / Cr_2O_3(c, \omega), OH^-$	0.018 1.499	
$Cr_2O_7^{2-}, H^+ / Cr_2O_5(c)$	(1.3) (-0.7)		$CrO_4^{2-} /$	-0.09 -1.66	
$HCrO_4^-, H^+ / CrOH^{2+}$	1.29	-1.17	$Cr(OH)_3(pt, aged), OH^-$		
$Cr_2O_7^{2-}, H^+ / CrOH^{2+}$	1.28	-1.10	$CrO_4^{2-} /$	-0.12 (-1.62)	
$H_3CrO_4, H^+ / Cr(OH)_2^{2+}$	(1.2)		$Cr(OH)_3(pt, fresh), OH^-$		
$Cr_2O_7^{2-}, H^+ / H_3CrO_4$	(1.1)		$CrO_4^{2-} / Cr(OH)_4^-, OH^-$	-0.14 (-1.32)	
$HCrO_4^-, H^+ / Cr(c)$	0.318	-0.471	$CrO_4^{2-} / CrO_2(c), OH^-$	(-0.14) <sup>b</sup> (-1.61)	
$Cr_2O_7^{2-}, H^+ / Cr(c)$	0.310	-0.439	$CrO_3^{3-} / CrO_2(c), OH^-$	(-0.4)	
$CrOH^{2+}, H^+ / Cr(c)$	-0.19	(0.7)	$CrO_3^{3-} / CrO_2(pt), OH^-$	(-0.6)	
$Cr_2(OH)_2^{4+}, H^+ / Cr(c)$	-0.26		$CrO_4^{2-} / Cr(OH)_6^{2-}, OH^-$	(-0.6)	
$Cr^{3+} / Cr^{2+}$	-0.42	(1.4)	$CrO_4^{2-} / Cr(c), OH^-$	-0.722 -1.354	
$CrOH^{2+}, H^+ / Cr(c)$	-0.66	0.22	$Cr(OH)_4^-, Cr(OH)_2(c), OH^-$	-1.14 (-1.4)	
$Cr_2(OH)_2^{4+}, H^+ / Cr(c)$	-0.68		$Cr(OH)_4^-, Cr(OH)_2(pt), OH^-$	-1.20	
$Cr^{3+} / Cr(c)$	-0.74	0.44	$Cr(OH)_3(pt, fresh) /$	-1.26	
$Cr^{2+} / Cr(c)$	-0.89	(-0.04)	$Cr(OH)_2(pt), OH^-$		
			$Cr_2O_3(c, \alpha) / Cr_3O_4(c), OH^-$	(-1.27) <sup>b</sup> (-1.07)	
			$Cr(OH)_4^-, Cr(c), OH^-$	-1.31 (-1.19)	
			$CrOOH(c) / Cr_3O_4(c), OH^-$	(-1.31) <sup>b</sup> (-0.43)	
			$Cr(OH)_3(pt, fresh) /$	-1.33 (-1.09)	
			$Cr(c), OH^-$		
			$Cr(OH)_3(pt, aged) /$	-1.35	
			$Cr(OH)_2(pt), OH^-$		
			$Cr(OH)_3(pt, aged) /$	-1.36 -1.05	
			$Cr(c), OH^-$		

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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## Chromium -- Continued

$\text{Cr}(\text{OH})_2$ (pt) / $\text{Cr}$ (c), $\text{OH}^-$	-1.36
$\text{CrO}$ (c) / $\text{Cr}$ (c), $\text{OH}^-$	(-1.38) <sup>a</sup> (-1.23)
$\text{Cr}(\text{OH})_2$ (c) / $\text{Cr}$ (c), $\text{OH}^-$	-1.39 (-1.08)
$\text{Cr}_2\text{O}_3$ (c, $\alpha$ ) / $\text{Cr}$ (c), $\text{OH}^-$	-1.427 -1.209
$\text{CrOOH}$ (c) / $\text{Cr}$ (c), $\text{OH}^-$	(-1.43) <sup>b</sup> (-1.14)
$\text{Cr}_3\text{O}_4$ (c) / $\text{Cr}$ (c), $\text{OH}^-$	(-1.45) <sup>b</sup> (-1.23)
$\text{Cr}_2\text{O}_3$ (c, $\alpha$ ) /	-1.50 (-1.5)
$\text{Cr}(\text{OH})_2$ (c), $\text{OH}^-$	
$\text{CrOOH}$ (c) /	(-1.5) (-1.3)
$\text{Cr}(\text{OH})_2$ (c), $\text{OH}^-$	
$\text{Cr}_2\text{O}_3$ (c, $\alpha$ ) / $\text{CrO}$ (c), $\text{OH}^-$	(-1.5) <sup>a</sup> (-1.2)
$\text{Cr}_3\text{O}_4$ (c) / $\text{Cr}(\text{OH})_2$ (c), $\text{OH}^-$	(-1.6) (-1.7)
$\text{Cr}_3\text{O}_4$ (c) / $\text{CrO}$ (c), $\text{OH}^-$	(-1.6) <sup>a</sup> (-1.2)

Molybdenum<sup>6-9</sup>

$\text{MoO}_3$ (c), $\text{H}^+$ /	(0.7) <sup>a</sup> (-0.4)	$\text{MoO}_4^{3-}$ / $\text{MoO}_2$ (c), $\text{OH}^-$	(-0.6) <sup>a</sup>
$\text{Mo}_2\text{O}_5$ (c)		$\text{Mo}(\text{OH})_3$ (pt) / $\text{Mo}$ (c), $\text{OH}^-$	(-0.8)
$\text{H}_2\text{MoO}_4$ (c), $\text{H}^+$ /	(0.6) <sup>a</sup> (-0.1)	$\text{MoO}_4^{2-}$ / $\text{MoO}_2$ (c), $\text{OH}^-$	-0.818 -1.69
$\text{Mo}_2\text{O}_5$ (c)		$\text{MoO}_4^{3-}$ / $\text{MoO}_2$ (pt), $\text{OH}^-$	(-0.9) <sup>a</sup>
$\text{H}_3\text{Mo}_7\text{O}_{24}^{3-}$ , $\text{H}^+$ /	(0.6)	$\text{MoO}_2$ (pt) / $\text{Mo}$ (c), $\text{OH}^-$	(-0.92)
$\text{Mo}_2\text{O}_4^{2-}$		$\text{MoO}_4^{2-}$ / $\text{Mo}$ (c), $\text{OH}^-$	-0.926 -1.36
$\text{MoO}_3$ (c), $\text{H}^+$ / $\text{MoO}_2$ (c)	0.530 -0.477	$\text{MoO}_4^{2-}$ / $\text{MoO}_2$ (pt), $\text{OH}^-$	(-0.94)
$\text{H}_3\text{Mo}_7\text{O}_{24}^{3-}$ , $\text{H}^+$ /	(0.5) <sup>a</sup>	$\text{MoO}_2$ (c) / $\text{Mo}$ (c), $\text{OH}^-$	-0.980 -1.196
$\text{MoO}(\text{OH})_3$ (pt)		$\text{MoO}_4^{2-}$ / $\text{MoO}_4^{3-}$	(-1.0) <sup>a</sup>
$\text{H}_2\text{MoO}_4$ (c), $\text{H}^+$ /	(0.49) <sup>b</sup> (-0.33)	$\text{MoO}_2$ (pt) /	(-1.3)
$\text{MoO}_2$ (c)		$\text{Mo}(\text{OH})_3$ (pt), $\text{OH}^-$	
$\text{H}_3\text{Mo}_7\text{O}_{24}^{3-}$ , $\text{H}^+$ /	(0.43)		
$\text{MoO}_2$ (pt)			
$\text{H}_3\text{Mo}_7\text{O}_{24}^{3-}$ , $\text{H}^+$ /	(0.4)		
$\text{Mo}_2\text{O}_4^{4+}$			
$\text{Mo}_2\text{O}_5$ (c), $\text{H}^+$ /	(0.4) <sup>a</sup> (-0.6)		
$\text{MoO}_2$ (c)			
$\text{MoO}(\text{OH})_3$ (pt), $\text{H}^+$ /	(0.4) <sup>a</sup>		
$\text{MoO}_2$ (pt)			
$\text{Mo}_2\text{O}_4^{2+}$ , $\text{H}^+$ / $\text{Mo}_2\text{O}_4^{4+}$	(0.2)		
$\text{Mo}_2\text{O}_4^{4+}$ , $\text{H}^+$ / $\text{Mo}^{3+}$	(0.1)		
$\text{H}_3\text{Mo}_7\text{O}_{24}^{3-}$ , $\text{H}^+$ / $\text{Mo}$ (c)	0.082 -0.384		
$\text{MoO}_3$ (c), $\text{H}^+$ / $\text{Mo}$ (c)	0.075 -0.399		
$\text{H}_2\text{MoO}_4$ (c), $\text{H}^+$ / $\text{Mo}$ (c)	(0.06) <sup>b</sup> (-0.35)		
$\text{MoO}_2$ (pt), $\text{H}^+$ / $\text{Mo}^{3+}$	(0.0)		
$\text{Mo}_2\text{O}_4^{4+}$ , $\text{H}^+$ / $\text{Mo}$ (c)	(-0.07)		
$\text{MoO}_2$ (pt), $\text{H}^+$ / $\text{Mo}$ (c)	(-0.09)		
$\text{Mo}_2^{4+}$ / $\text{Mo}$ (c)	(-0.1)		
$\text{Mo}^{3+}$ / $\text{Mo}$ (c)	(-0.13)		
$\text{MoO}_2$ (c), $\text{H}^+$ / $\text{Mo}$ (c)	-0.152 -0.360		
$\text{Mo}^{3+}$ / $\text{Mo}_2^{4+}$	(-0.2)		
$\text{MoO}_2$ (c), $\text{H}^+$ / $\text{Mo}^{3+}$	(-0.2)		

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Tungsten<sup>6-9</sup>

$\text{W}^{3+}$ / $\text{W}$ (c)	(0.1) <sup>a</sup>	$\text{W}(\text{OH})_3$ (pt) / $\text{W}$ (c), $\text{OH}^-$	(-0.6) <sup>a</sup>
$\text{H}_2\text{WO}_4$ (c), $\text{H}^+$ / $\text{WO}_2$ (c)	(0.06) <sup>b</sup> (-0.31)	$\text{WO}_2$ (pt) / $\text{W}$ (c), $\text{OH}^-$	(-0.92)
$\text{WO}_3$ (c), $\text{H}^+$ / $\text{WO}_2$ (c)	0.036	$\text{WO}_2$ (c) / $\text{W}$ (c), $\text{OH}^-$	-0.982 -1.197
$\text{H}_2\text{W}_6\text{O}_{21}^{4-}$ , $\text{H}^+$ /	(0.01)	$\text{WO}_4^{2-}$ / $\text{W}$ (c), $\text{OH}^-$	-1.060 -1.36
$\text{WO}_2$ (pt)		$\text{WO}_4^{2-}$ / $\text{WO}_2$ (pt), $\text{OH}^-$	-1.217 -1.69
$\text{W}(\text{OH})_2^{2+}$ , $\text{H}^+$ / $\text{W}$ (c)	(-0.05)	$\text{WO}_4^{2-}$ / $\text{WO}_2$ (pt), $\text{OH}^-$	(-1.34)
$\text{H}_2\text{W}_6\text{O}_{21}^{4-}$ , $\text{H}^+$ / $\text{W}$ (c)	(-0.06) (-0.33)	$\text{WO}_2$ (pt) /	(-1.7) <sup>a</sup>
$\text{H}_2\text{W}_6\text{O}_{21}^{4-}$ , $\text{H}^+$ /	(-0.07)	$\text{W}(\text{OH})_3$ (pt), $\text{OH}^-$	
$\text{W}(\text{OH})_2^{2+}$			
$\text{H}_2\text{WO}_4$ (c), $\text{H}^+$ / $\text{W}$ (c)	(-0.08) <sup>b</sup> (-0.34)		
$\text{WO}_2$ (pt), $\text{H}^+$ / $\text{W}$ (c)	(-0.09)		
$\text{WO}_3$ (c), $\text{H}^+$ / $\text{W}$ (c)	-0.091	$\text{WO}_2$ (c), $\text{H}^+$ / $\text{W}$ (c)	-0.389
$\text{WO}_2$ (c), $\text{H}^+$ / $\text{W}$ (c)	-0.154	$\text{WO}_4^{2-}$ / $\text{W}$ (c)	-0.361
$\text{W}(\text{OH})_2^{2+}$ , $\text{H}^+$ / $\text{W}^{3+}$	(-0.5) <sup>a</sup>		
$\text{WO}_2$ (pt), $\text{H}^+$ / $\text{W}^{3+}$	(-0.7) <sup>a</sup>		
$\text{WO}_2$ (c), $\text{H}^+$ / $\text{W}^{3+}$	(-0.9) <sup>a</sup>		

Manganese<sup>6-10</sup>

$\text{H}_3\text{MnO}_4$ , $\text{H}^+$ /	(2.9)	$\text{MnO}_4^{3-}$ / $\text{MnO}_2$ (c, $\beta$ ), $\text{OH}^-$	0.93
$\text{MnO}_2$ (c, $\beta$ )		$\text{MnO}_4^{3-}$ / $\text{MnO}_2$ (pt), $\text{OH}^-$	(0.76)
$\text{H}_3\text{MnO}_4$ , $\text{H}^+$ / $\text{MnO}_2$ (pt)	(2.7)	$\text{MnO}_4^{3-}$ / $\text{Mn}(\text{OH})_2^{2-}$ , $\text{OH}^-$	(0.7)
$\text{H}_3\text{MnO}_4$ , $\text{H}^+$ /	(2.5)	$\text{MnO}_4^{2-}$ / $\text{MnO}_2$ (c, $\beta$ ), $\text{OH}^-$	0.60 -1.65
$\text{Mn}(\text{OH})_2^{2+}$		$\text{MnO}_4^{2-}$ / $\text{MnO}_2$ (c, $\beta$ ), $\text{OH}^-$	0.588 -1.785
$\text{HMnO}_4$ , $\text{H}^+$ /	(2.09)	$\text{MnO}_4^{2-}$ / $\text{MnO}_2$ (pt), $\text{OH}^-$	(0.31) <sup>b</sup> (-1.64)
$\text{HMnO}_4$ , $\text{H}^+$ /	(1.9)	$\text{MnO}_4^{2-}$ / $\text{Mn}(\text{OH})_2^{2-}$ , $\text{OH}^-$	(0.50)
$\text{Mn}(\text{OH})_2^{2+}$		$\text{MnO}_4^{2-}$ / $\text{Mn}(\text{OH})_2^{2-}$ , $\text{OH}^-$	(0.5)
$\text{MnO}_4^-$ , $\text{H}^+$ / $\text{MnO}_2$ (c, $\beta$ )	1.692 -0.671	$\text{MnO}_4^{2-}$ / $\text{MnO}_4^{3-}$	0.27
$\text{MnO}_4^-$ , $\text{H}^+$ / $\text{MnO}_2$ (pt)	(1.63) <sup>b</sup> (-0.66)	$\text{MnO}_2$ (c, $\beta$ ) /	0.15 (-1.4)
$\text{MnO}_4^-$ , $\text{H}^+$ / $\text{Mn}(\text{OH})_2^{2+}$	(1.57)	$\text{MnOOH}$ (c), $\text{OH}^-$	
$\text{Mn}^{3+}$ / $\text{Mn}^{2+}$	1.56 (1.8)	$\text{MnO}_2$ (c, $\beta$ ) /	0.146 -1.128
$\text{MnO}_4^-$ , $\text{H}^+$ / $\text{Mn}^{2+}$	1.507 -0.646	$\text{Mn}_2\text{O}_3$ (c), $\text{OH}^-$	
$\text{Mn}_2\text{O}_3$ (c), $\text{H}^+$ / $\text{Mn}^{2+}$	1.485 -0.926	$\text{Mn}(\text{OH})_3$ (pt) /	(0.05) (-0.9)
$\text{MnOOH}$ (c), $\text{H}^+$ / $\text{Mn}^{2+}$	1.48 (-0.7)	$\text{Mn}(\text{OH})_2$ (pt), $\text{OH}^-$	
$\text{Mn}(\text{OH})_2^{2+}$ , $\text{H}^+$ / $\text{Mn}^{2+}$	(1.41)	$\text{MnO}_2$ (pt) /	(0.04) <sup>b</sup> (-1.28)
$\text{MnO}_4^-$ , $\text{H}^+$ / $\text{MnOH}^+$	1.382 -0.648	$\text{Mn}(\text{OH})_2$ (pt), $\text{OH}^-$	
$\text{MnO}_2$ (pt), $\text{H}^+$ / $\text{Mn}^{2+}$	(1.32) <sup>b</sup> (-0.62)	$\text{MnO}_2$ (pt) /	(0.03) (-1.7)
$\text{HMnO}_4$ , $\text{H}^+$ / $\text{H}_3\text{MnO}_4$	(1.3)	$\text{Mn}(\text{OH})_3$ (pt), $\text{OH}^-$	
$\text{Mn}(\text{OH})_2^{2+}$ , $\text{H}^+$ / $\text{Mn}^{3+}$	(1.3)	$\text{Mn}_2\text{O}_3$ (c) /	0.002 -1.256
$\text{MnO}_2$ (c, $\beta$ ), $\text{H}^+$ / $\text{Mn}^{2+}$	1.230 -0.609	$\text{Mn}_3\text{O}_4$ (c), $\text{OH}^-$	
$\text{MnO}_2$ (pt), $\text{H}^+$ / $\text{Mn}^{3+}$	(1.08) (-3.0)	$\text{MnOOH}$ (c) /	-0.02 (-0.6)
$\text{MnO}_2$ (c, $\beta$ ), $\text{H}^+$ /	0.98 (-0.5)	$\text{Mn}_3\text{O}_4$ (c), $\text{OH}^-$	
$\text{MnOOH}$ (c)		$\text{MnO}_2$ (c, $\beta$ ) /	-0.044 -1.31
$\text{MnO}_2$ (c, $\beta$ ), $\text{H}^+$ /	0.974 -0.292	$\text{Mn}(\text{OH})_2$ (c), $\text{OH}^-$	
$\text{Mn}_2\text{O}_3$ (c)		$\text{Mn}(\text{OH})_2^{2-}$ /	(-0.1)
$\text{MnO}_2$ (c, $\beta$ ), $\text{H}^+$ / $\text{MnOH}^+$	0.916 -0.614	$\text{Mn}(\text{OH})_4^{2-}$ , $\text{OH}^-$	
$\text{MnO}_4^-$ , $\text{H}^+$ / $\text{HMnO}_4^-$	(0.90)	$\text{Mn}(\text{OH})_4^-$ / $\text{Mn}(\text{OH})_4^{2-}$	(-0.1)

## STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

9

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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## Manganese -- Continued

MnO <sub>2</sub> (c, β), H <sup>+</sup> / Mn <sup>3+</sup>	0.90	(-3.0)	MnO <sub>2</sub> (c, β) / MnO (c), OH <sup>-</sup>	-0.129	-1.116
Mn <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / MnOH <sup>-</sup>	0.838	-0.935	Mn <sub>2</sub> O <sub>3</sub> (c) /	-0.234	-1.49
MnOOH (c), H <sup>+</sup> / MnOH <sup>-</sup>	0.85	(-0.7)	Mn(OH) <sub>2</sub> (c), OH <sup>-</sup>		
MnOH <sup>-</sup> , H <sup>+</sup> / Mn (c)	-0.869	-0.125	MnOOH (c) /	-0.24	(-1.3)
Mn <sup>2+</sup> / Mn (c)	-1.182	-0.129	Mn(OH) <sub>2</sub> (c), OH <sup>-</sup>		
			Mn <sub>3</sub> O <sub>4</sub> (c) /	-0.352	-1.61
			Mn(OH) <sub>2</sub> (c), OH <sup>-</sup>		
Mn <sub>2</sub> O <sub>3</sub> (c) / MnO (c), OH <sup>-</sup>	-0.404	-1.104			
Mn <sub>3</sub> O <sub>4</sub> (c) / MnO (c), OH <sup>-</sup>	-0.607	-1.028			
Mn(OH) <sub>4</sub> <sup>2-</sup> / Mn (c), OH <sup>-</sup>	-1.42				
MnO (c) / Mn (c), OH <sup>-</sup>	-1.480	-1.294			
Mn(OH) <sub>2</sub> (pt) / Mn (c), OH <sup>-</sup>	-1.560	-1.14			
Mn(OH) <sub>2</sub> (c) / Mn (c), OH <sup>-</sup>	-1.565	-1.10			

 Technetium<sup>9</sup>

TcO <sub>3</sub> (c), H <sup>+</sup> / TcO <sub>2</sub> (c)	(0.76) <sup>a</sup>	(-0.5)	TcO <sub>4</sub> <sup>2-</sup> / TcO <sub>2</sub> (c), OH <sup>-</sup>	-0.26	
TcO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / TcO <sub>2</sub> (c)	0.738	(-0.70)	TcO <sub>4</sub> <sup>2-</sup> / TcO <sub>2</sub> (pt), OH <sup>-</sup>	(-0.29)	
TcO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / TcO <sub>2</sub> (pt)	(0.72)	(-0.68)	TcO <sub>4</sub> <sup>-</sup> / TcO <sub>2</sub> (c), OH <sup>-</sup>	-0.366	(-1.82)
TcO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / TcO <sub>3</sub> (c)	(0.70) <sup>a</sup>	(-1.2)	TcO <sub>4</sub> <sup>-</sup> / TcO <sub>2</sub> (pt), OH <sup>-</sup>	(-0.38)	(-1.80)
TcO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Tc(OH) <sub>2</sub> <sup>2+</sup>	(0.62)		Tc(OH) <sub>3</sub> (pt) / Tc (c), OH <sup>-</sup>	(-0.4)	
TcO <sub>2</sub> (c), H <sup>+</sup> / Tc(OH) <sub>2</sub> <sup>2+</sup>	(0.38) <sup>a</sup>		TcO <sub>2</sub> <sup>2-</sup> / Tc(OH) <sub>2</sub> <sup>2-</sup> , OH <sup>-</sup>	(-0.4)	
Tc(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Tc <sup>3+</sup>	(0.5)		TcO <sub>4</sub> <sup>-</sup> / Tc(OH) <sub>2</sub> <sup>2-</sup> , OH <sup>-</sup>	(-0.46)	
TcO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Tc (c)	0.472	(-0.51)	TcO <sub>4</sub> <sup>-</sup> / Tc (c), OH <sup>-</sup>	-0.474	(-1.46)
Tc(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Tc (c)	(0.36)		Tc(OH) <sub>6</sub> <sup>2-</sup> / Tc (c), OH <sup>-</sup>	(-0.48)	
Tc <sup>3+</sup> / Tc <sup>2+</sup>	(0.3) <sup>a</sup>		TcO <sub>2</sub> (pt) / Tc (c), OH <sup>-</sup>	(-0.55)	(-1.21)
Tc <sup>2+</sup> / Tc (c)	(0.3) <sup>a</sup>		TcO <sub>2</sub> (c) / Tc (c), OH <sup>-</sup>	-0.556	(-1.20)
TcO <sub>2</sub> (pt), H <sup>+</sup> / Tc (c)	(0.28)	(-0.37)	TcO <sub>4</sub> <sup>-</sup> / TcO <sub>4</sub> <sup>2-</sup>	-0.57	
TcO <sub>2</sub> (c), H <sup>+</sup> / Tc (c)	0.272	(-0.36)	Tc(OH) <sub>6</sub> <sup>2-</sup> /	(-0.8)	
TcO <sub>2</sub> (pt), H <sup>+</sup> / Tc <sup>3+</sup>	(0.2)		TcO <sub>2</sub> (pt) / Tc(OH) <sub>3</sub> (pt), OH <sup>-</sup>	(-1.1)	

## Rhodium 6, 7, 9, 10

ReO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / ReO <sub>3</sub> (c)	(0.72) <sup>b</sup>	(-1.17)	Re(OH) <sub>3</sub> (pt) /	(-0.28) <sup>b</sup>	(-1.07)
ReO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / ReO <sub>2</sub> (c)	0.510	(-0.70)	Re (c), OH <sup>-</sup>		
Re <sup>3+</sup> / Re (c)	(0.3)		Re <sub>2</sub> O <sub>5</sub> (c) /	(-0.4)	(-1.3)
ReO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / ReO <sub>2</sub> (pt)	(0.49) <sup>b</sup>	(-0.68)	ReO <sub>2</sub> (c), OH <sup>-</sup>		
ReO <sub>3</sub> (c), H <sup>+</sup> / Re <sub>2</sub> O <sub>5</sub> (c)	(0.4)	(-0.4)	Re(OH) <sub>6</sub> <sup>2-</sup> / Re (c), OH <sup>-</sup>	(-0.47)	
ReO <sub>3</sub> (c), H <sup>+</sup> / ReO <sub>2</sub> (c)	(0.40) <sup>b</sup>	(-0.47)	ReO <sub>4</sub> <sup>2-</sup> / ReO <sub>2</sub> (c), OH <sup>-</sup>	(-0.5)	
Re <sub>2</sub> O <sub>5</sub> (c), H <sup>+</sup> / ReO <sub>2</sub> (c)	(0.4)	(-0.5)	ReO <sub>4</sub> <sup>2-</sup> / ReO <sub>2</sub> (pt), OH <sup>-</sup>	(-0.5)	
Re(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Re (c)	(0.39)		ReO <sub>2</sub> (pt) / Re (c), OH <sup>-</sup>	(-0.54) <sup>b</sup>	(-1.21)
ReO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Re (c)	0.376	-0.506	ReO <sub>2</sub> (c) / Re (c), OH <sup>-</sup>	-0.532	(-1.20)
ReO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Re(OH) <sub>2</sub> <sup>2+</sup>	(0.36)		ReO <sub>4</sub> <sup>-</sup> / Re (c), OH <sup>-</sup>	-0.570	-1.461
ReO <sub>2</sub> (pt), H <sup>+</sup> / Re (c)	(0.29) <sup>b</sup>	(-0.37)	ReO <sub>4</sub> <sup>-</sup> / ReO <sub>2</sub> (c), OH <sup>-</sup>	-0.594	(-1.82)
ReO <sub>2</sub> (c), H <sup>+</sup> / Re (c)	0.276	(-0.36)	ReO <sub>4</sub> <sup>2-</sup> / Re <sub>2</sub> O <sub>5</sub> (c), OH <sup>-</sup>	(-0.6)	
ReO <sub>3</sub> (c), H <sup>+</sup> /	(0.18)		ReO <sub>4</sub> <sup>2-</sup> / ReO <sub>2</sub> (pt), OH <sup>-</sup>	(-0.61) <sup>b</sup>	(-1.80)
Re(OH) <sub>2</sub> <sup>2+</sup>			ReO <sub>4</sub> <sup>2-</sup> / Re(OH) <sub>6</sub> <sup>2-</sup> , OH <sup>-</sup>	(-0.7)	
Re(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Re <sup>3+</sup>	(0.0)		ReO <sub>4</sub> <sup>-</sup> / Re(OH) <sub>6</sub> <sup>2-</sup> , OH <sup>-</sup>	(-0.70)	
Re (c), H <sup>+</sup> / ReH	-0.1 <sup>a</sup>	1.3	ReO <sub>4</sub> <sup>2-</sup> / ReO <sub>4</sub> <sup>2-</sup>	(-0.8)	
ReO <sub>2</sub> (pt), H <sup>+</sup> / Re <sup>3+</sup>	(-0.3)		Re (c) / ReH, OH <sup>-</sup>	-0.9 <sup>a</sup>	0.5

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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## Rhodium -- Continued

ReO <sub>2</sub> (c), H <sup>+</sup> / Re <sup>3+</sup>	(-0.4)		Re(OH) <sub>6</sub> <sup>2-</sup> /	(-1.0)	
Re(OH) <sub>3</sub> (pt), OH <sup>-</sup>			Re(OH) <sub>3</sub> (pt), OH <sup>-</sup>	(-1.3) <sup>b</sup>	(-1.6)
ReO <sub>2</sub> (pt) /			Re(OH) <sub>3</sub> (pt), OH <sup>-</sup>		
Re(OH) <sub>3</sub> (pt), OH <sup>-</sup>					

## Iron 2, 6-9

HFeO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Fe <sub>2</sub> O <sub>3</sub> (c, α)	(2.09)		FeO <sub>4</sub> <sup>2-</sup> / Fe <sub>2</sub> O <sub>3</sub> (c, α), OH <sup>-</sup>	(0.81) <sup>b</sup>	(-1.52)
HFeO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / FeOOH (c)	(2.08)		FeO <sub>4</sub> <sup>2-</sup> / FeOOH (c), OH <sup>-</sup>	(0.80) <sup>b</sup>	(-1.59)
HFeO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Fe <sup>3+</sup>	(2.07)		FeO <sub>4</sub> <sup>2-</sup> / Fe(OH) <sub>3</sub> (pt), OH <sup>-</sup>	(0.71) <sup>b</sup>	(-1.67)
HFeO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Fe <sub>2</sub> (OH) <sub>2</sub> <sup>4+</sup>	(2.04)		FeO <sub>4</sub> <sup>2-</sup> / Fe(OH) <sub>4</sub> <sup>-</sup> , OH <sup>-</sup>	(0.64)	(-1.55)
HFeO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / FeOH <sup>2+</sup>	(2.03)		Fe(OH) <sub>3</sub> (pt) /	-0.55	(-0.94)
FeOH <sup>2+</sup> , H <sup>+</sup> / Fe <sup>2+</sup>	0.900	0.096	Fe(OH) <sub>2</sub> (pt), OH <sup>-</sup>		
Fe <sub>2</sub> (OH) <sub>2</sub> <sup>4+</sup> , H <sup>+</sup> / Fe <sup>2+</sup>	0.858	0.485	FeOOH (c) / Fe <sub>3</sub> O <sub>4</sub> (c), OH <sup>-</sup>	(-0.36) <sup>b</sup>	(-0.38)
Fe <sup>3+</sup> / Fe <sup>2+</sup>	0.771	1.175	Fe <sub>2</sub> O <sub>3</sub> (c, α) / Fe <sub>3</sub> O <sub>4</sub> (c), OH <sup>-</sup>	-0.615	-0.992
FeOOH (c), H <sup>+</sup> / Fe <sup>2+</sup>	(0.74) <sup>b</sup>	(1.05)	Fe(OH) <sub>4</sub> <sup>-</sup> / Fe(OH) <sub>4</sub> <sup>2-</sup>	0.68	
Fe <sub>2</sub> O <sub>3</sub> (c, α), H <sup>+</sup> / Fe <sup>2+</sup>	0.72	-1.25	Fe(OH) <sub>4</sub> <sup>-</sup> / Fe (c), OH <sup>-</sup>	-0.71	(-1.18)
FeOOH (c), H <sup>+</sup> / FeOH <sup>+</sup>	(0.18) <sup>b</sup>	(-1.06)	Fe(OH) <sub>4</sub> <sup>-</sup> / Fe (c), OH <sup>-</sup>	-0.73	
Fe <sub>2</sub> O <sub>3</sub> (c, α), H <sup>+</sup> / FeOH <sup>+</sup>	0.16	-1.26	Fe(OH) <sub>3</sub> (pt) / Fe (c), OH <sup>-</sup>	-0.776	-1.062
FeOH <sup>+</sup> , H <sup>+</sup> / Fe (c)	-0.16	0.07	FeOOH (c) /		(-0.84) <sup>b</sup>
Fe <sup>2+</sup> / Fe (c)	-0.44	0.07	Fe(OH) <sub>2</sub> (c), OH <sup>-</sup>		
Fe <sub>2</sub> O <sub>3</sub> (c, α) /			Fe <sub>2</sub> O <sub>3</sub> (c, α) /	-0.86	-1.43
Fe(OH) <sub>2</sub> (c), OH <sup>-</sup>			Fe(OH) <sub>2</sub> (c), OH <sup>-</sup>	-0.870	-1.314
Fe <sub>0.9470</sub> (c) / Fe (c), OH <sup>-</sup>			FeOOH (c) / Fe (c), OH <sup>-</sup>	(-0.87) <sup>b</sup>	(-1.14)
Fe <sub>2</sub> O <sub>3</sub> (c, α) / Fe (c), OH <sup>-</sup>			Fe <sub>2</sub> O <sub>3</sub> (c, α) / Fe (c), OH <sup>-</sup>	-0.881	-1.207
Fe(OH) <sub>2</sub> (pt) / Fe (c), OH <sup>-</sup>			Fe(OH) <sub>2</sub> (c) / Fe (c), OH <sup>-</sup>	-0.89	(-1.12)
Fe(OH) <sub>2</sub> (c) / Fe (c), OH <sup>-</sup>			Fe(OH) <sub>2</sub> (c) / Fe (c), OH <sup>-</sup>	-0.89	-1.09
Fe <sub>2</sub> O <sub>3</sub> (c, α) /			Fe <sub>2</sub> O <sub>3</sub> (c, α) /	-0.909	-0.952
Fe <sub>0.9470</sub> (c), OH <sup>-</sup>			Fe <sub>0.9470</sub> (c), OH <sup>-</sup>		
Fe <sub>3</sub> O <sub>4</sub> (c) / Fe (c), OH <sup>-</sup>			Fe <sub>3</sub> O <sub>4</sub> (c) / Fe (c), OH <sup>-</sup>	-0.914	-1.234
Fe <sub>2</sub> O <sub>4</sub> (c) / Fe(OH) <sub>2</sub> (c), OH <sup>-</sup>			Fe <sub>2</sub> O <sub>4</sub> (c) / Fe(OH) <sub>2</sub> (c), OH <sup>-</sup>	-0.98	-1.65
Fe <sub>3</sub> O <sub>4</sub> (c) / Fe <sub>0.9470</sub> (c), OH <sup>-</sup>			Fe <sub>3</sub> O <sub>4</sub> (c) / Fe <sub>0.9470</sub> (c), OH <sup>-</sup>	-1.085	-0.927

## Ruthenium 6-10

RuO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / RuO <sub>3</sub> (c)	(1.9) <sup>a</sup>		RuO <sub>4</sub> OH <sup>-</sup> / RuO <sub>4</sub> <sup>-</sup> , OH <sup>-</sup>	0.85	
RuO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / RuO <sub>2</sub> (c)	(1.66)		RuO <sub>4</sub> OH <sup>-</sup> / RuO <sub>2</sub> (c), OH <sup>-</sup>	(0.63)	
RuO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / RuO <sub>2</sub> <sup>2+</sup>	(1.6) <sup>a</sup>		RuO <sub>4</sub> <sup>-</sup> / RuO <sub>4</sub> <sup>2-</sup>	0.59	
RuO <sub>4</sub> <sup>-</sup> , H <sup>+</sup> / Ru(OH) <sub>2</sub> <sup>2+</sup>	1.53		RuO <sub>4</sub> OH <sup>-</sup> / RuO <sub>2</sub> (pt), OH <sup>-</sup>	0.54	
RuO <sub>3</sub> (c), H <sup>+</sup> / RuO <sub>2</sub> (c)	(1.5) <sup>a</sup>		RuO <sub>4</sub> OH <sup>-</sup> / Ru(OH) <sub>6</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.54)	
RuO <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Ru(OH) <sub>2</sub> <sup>2+</sup>	(1.5) <sup>a</sup>		RuO <sub>4</sub> <sup>-</sup> / RuO <sub>2</sub> (c), OH <sup>-</sup>	(0.54)	
RuO <sub>4</sub> (c), H <sup>+</sup> / RuO <sub>2</sub> (c)	(1.48) <sup>b</sup>	(-0.58)	RuO <sub>4</sub> <sup>-</sup> / RuO <sub>2</sub> (pt), OH <sup>-</sup>	0.35	
RuO <sub>4</sub> (c), H <sup>+</sup> / RuO <sub>3</sub> (c)	(1.4) <sup>a</sup>		RuO <sub>4</sub> <sup>-</sup> / RuO <sub>2</sub> (c), OH <sup>-</sup>	(0.3)	
RuO <sub>4</sub> (c), H <sup>+</sup> / RuO <sub>2</sub> <sup>2+</sup>	1.40		RuO <sub>4</sub> OH <sup>-</sup> / Ru (c), OH <sup>-</sup>	0.193	
RuO <sub>4</sub> , H <sup>+</sup> / RuO <sub>2</sub> <sup>2+</sup>	(1.3) <sup>a</sup>		Ru(OH) <sub>4</sub> <sup>-</sup> / Ru (c), OH <sup>-</sup>	(0.0)	
RuO <sub>4</sub> , H <sup>+</sup> / Ru (c)	1.038	-0.446	Ru(OH) <sub>3</sub> (pt) / Ru (c), OH <sup>-</sup>	(-0.06)	
RuO <sub>4</sub> , H <sup>+</sup> / RuO <sub>4</sub> <sup>-</sup>	0.99		Ru(OH) <sub>2</sub> <sup>2+</sup> / Ru (c), OH <sup>-</sup>	(-0.15)	
RuO <sub>2</sub> (c) / RuO <sub>4</sub> <sup>-</sup>	0.94		RuO <sub>2</sub> (c) / Ru (c), OH <sup>-</sup>	(-0.25) <sup>b</sup>	(-1.20)

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Ruthenium -- Continued</b>					
$\text{Ru(OH}_2^{2+}, \text{H}^+ / \text{Ru}^{3+}$	(0.9)		$\text{RuO}_2$ (pt) /		(-0.4)
$\text{Ru}^{2+} / \text{Ru}$ (c)	(0.8)		$\text{Ru(OH}_3$ (pt), $\text{OH}^-$		
$\text{Ru(OH}_2^{2+}, \text{H}^+ / \text{Ru}$ (c)	0.68		$\text{Ru(OH}_6^{2-} / \text{Ru(OH}_4^{+}, \text{OH}^-$	(-0.6)	
$\text{Ru}^{3+} / \text{Ru}$ (c)	(0.60)				
$\text{RuO}_2$ (c), $\text{H}^+ / \text{Ru}$ (c)	(0.58) <sup>b</sup>	(-0.36)			
$\text{RuO}_2$ (c), $\text{H}^+ / \text{Ru}^{3+}$	(0.5)				
$\text{Ru}^{3+} / \text{Ru}^{2+}$	0.24				
<b>Osmium 1, 6-9</b>					
$\text{OsO}_2^{2+} / \text{OsO}_2$ (pt)	(1.2) <sup>a</sup>		$\text{OsO}_3(\text{OH})_3^{2-} /$		(0.3)
$\text{OsO}_3$ (c), $\text{H}^+ / \text{OsO}_2$ (c)	(1.1) <sup>a</sup>		$\text{OsO}_2(\text{OH})_4^{2-}, \text{OH}^-$		
$\text{OsO}_2^{2+}, \text{H}^+ / \text{Os(OH}_2^{2+}$	(1.1) <sup>a</sup>		$\text{OsO}_4\text{OH}^- / \text{OsO}_2(\text{OH})_3^{2-}, \text{OH}^-$	(0.3)	
$\text{OsO}_4$ (c, y), $\text{H}^+ / \text{OsO}_2$ (c)	1.02	(-0.36)	$\text{OsO}_4\text{OH}^- / \text{OsO}_3(\text{OH})_3^{2-}$	(0.2)	
$\text{OsO}_4$ , $\text{H}^+ / \text{OsO}_2$ (pt)	0.964		$\text{Os(OH}_6^{3-} / \text{Os}$ (c), $\text{OH}^-$	(0.2)	
$\text{OsO}_4$ , $\text{H}^+ / \text{Os(OH}_2^{2+}$	(0.91)		$\text{OsO}_4\text{OH}^- / \text{OsO}_2$ (c), $\text{OH}^-$	0.17	
$\text{OsO}_4$ (c, y), $\text{H}^+ / \text{OsO}_3$ (c)	(0.9) <sup>a</sup>		$\text{OsO}_4\text{OH}^- / \text{OsO}_2$ (pt), $\text{OH}^-$	0.108	
$\text{Os}^{3+} / \text{Os}$ (c)	(0.9)		$\text{Os(OH}_3$ (pt) / $\text{Os}$ (c), $\text{OH}^-$	(0.1)	
$\text{OsO}_4$ , $\text{H}^+ / \text{Os}$ (c)	0.838	-0.314	$\text{OsO}_2(\text{OH})_2^{2-} / \text{OsO}_2$ (c), $\text{OH}^-$	(0.1)	
$\text{OsO}_4$ (c, y), $\text{H}^+ / \text{Os}$ (c)	0.834	-0.458	$\text{OsO}_4\text{OH}^- / \text{Os(OH}_6^{2-}, \text{OH}^-$	(0.09)	
$\text{Os(OH}_2^{2+}, \text{H}^+ / \text{Os}$ (c)	(0.76)		$\text{OsO}_4\text{OH}^- / \text{Os}$ (c), $\text{OH}^-$	-0.004	
$\text{OsO}_2$ (pt), $\text{H}^+ / \text{Os}$ (c)	0.712		$\text{Os(OH}_6^{2-} / \text{Os}$ (c), $\text{OH}^-$	(-0.09)	
$\text{OsO}_4$ , $\text{H}^+ / \text{OsO}_2^{2+}$	(0.7) <sup>a</sup>		$\text{OsO}_2(\text{OH})_4^{2-} / \text{OsO}_2$ (pt), $\text{OH}^-$	(-0.1)	
$\text{OsO}_2$ (c), $\text{H}^+ / \text{Os}$ (c)	0.65	(-0.36)	$\text{OsO}_2(\text{OH})_2^{2-} /$	(-0.1)	
$\text{Os(OH}_2^{2+}, \text{H}^+ / \text{Os}^{3+}$	(0.4)		$\text{Os(OH}_6^{2-}, \text{OH}^-$		
$\text{OsO}_2$ (pt), $\text{H}^+ / \text{Os}^{3+}$	(0.2)		$\text{OsO}_2$ (pt) / $\text{Os}$ (c), $\text{OH}^-$	-0.116	
$\text{OsO}_2$ (c), $\text{H}^+ / \text{Os}^{3+}$	(-0.1)		$\text{OsO}_2$ (c) / $\text{Os}$ (c), $\text{OH}^-$	-0.18	(-1.20)
$\text{OsO}_2$ (pt) / $\text{Os(OH}_3$ (pt), $\text{OH}^-$			$\text{OsO}_2$ (pt) / $\text{Os(OH}_3$ (pt), $\text{OH}^-$	(-0.8)	
$\text{Os(OH}_6^{2-} / \text{Os(OH}_5^{3-}$			$\text{Os(OH}_6^{2-} / \text{Os(OH}_5^{3-}$	(-0.8)	
<b>Cobalt 6-9</b>					
$\text{H}_3\text{CoO}_4$ , $\text{H}^+ / \text{CoO}_2$ (c)	(3.0) <sup>a</sup>		$\text{CoO}_4^{3-} / \text{CoO}_2$ (c), $\text{OH}^-$	(1.0) <sup>a</sup>	
$\text{Co}^{3+} / \text{Co}^{2+}$	1.92	1.23	$\text{CoO}_2$ (c) / $\text{Co}_2\text{O}_3$ (c), $\text{OH}^-$	(0.9) (-1.2)	
$\text{CoOOH}$ (c), $\text{H}^+ / \text{Co}^{2+}$	(1.76) <sup>b</sup>	(-1.01)	$\text{CoO}_2$ (c) / $\text{CoOOH}$ (c), $\text{OH}^-$	(0.8) (-1.4)	
$\text{CoO}_2$ (c), $\text{H}^+ / \text{Co}_2\text{O}_3$ (c)	(1.7)	(-0.4)	$\text{CoO}_4^{3-} / \text{Co(OH}_3$ (pt), $\text{OH}^-$	(0.7) <sup>a</sup>	
$\text{CoO}_2$ (c), $\text{H}^+ / \text{Co}^{2+}$	(1.7)	(-0.8)	$\text{CoO}_4^{3-} / \text{Co(OH}_4^{+}, \text{OH}^-$	(0.7) <sup>a</sup>	
$\text{Co}_2\text{O}_3$ (c), $\text{H}^+ / \text{Co}^{2+}$	(1.6)	(-1.2)	$\text{CoOOH}$ (c) / $\text{Co}_3\text{O}_4$ (c), $\text{OH}^-$	(0.70) <sup>b</sup>	(-0.55)
$\text{CoO}_2$ (c), $\text{H}^+ / \text{CoOOH}$ (c)	(1.6)	(-0.6)	$\text{Co(OH}_3$ (pt) /	(0.5) (-1.1)	
$\text{CoO}_2$ (c), $\text{H}^+$	(1.5)		$\text{Co(OH}_2$ (pt, pk), $\text{OH}^-$		
$\text{Co}_4(\text{OH})_4^{4+}$			$\text{Co(OH}_3$ (pt) /	(0.4)	
$\text{CoO}_2$ (c), $\text{H}^+ / \text{Co}^{3+}$	(1.4)	(-2.8)	$\text{Co(OH}_2$ (pt, bl), $\text{OH}^-$		
$\text{CoO}_2$ (c), $\text{H}^+ / \text{CoOH}^+$	(1.4)	(-0.7)	$\text{Co}_2\text{O}_3$ (c) / $\text{Co}_3\text{O}_4$ (c), $\text{OH}^-$	(0.3) (-1.1)	
$\text{CoOOH}$ (c), $\text{H}^+$	(1.31)		$\text{CoOOH}$ (c) / $\text{Co(OH}_2$ (c), $\text{OH}^-$	(0.20) <sup>b</sup>	(-1.35)
$\text{Co}_4(\text{OH})_4^{4+}$			$\text{Co(OH}_4^{+} / \text{Co(OH}_4^{2-}$	(0.2)	
$\text{Co}_2\text{O}_3$ (c), $\text{H}^+$	(1.2)		$\text{Co}_2\text{O}_3$ (c) / $\text{Co(OH}_2$ (c), $\text{OH}^-$	(0.1) (-1.5)	
$\text{Co}_4(\text{OH})_4^{4+}$			$\text{Co}_2\text{O}_3$ (c) / $\text{Co}$ (c), $\text{OH}^-$	(0.0) (-1.0)	
$\text{CoOOH}$ (c), $\text{H}^+ / \text{CoOH}^+$	(1.19) <sup>b</sup>	(-0.80)	$\text{Co}_3\text{O}_4$ (c) / $\text{Co(OH}_2$ (c), $\text{OH}^-$	-0.05	-1.75
$\text{Co}_2\text{O}_3$ (c), $\text{H}^+ / \text{CoOH}^+$	(1.1)	(-1.0)	$\text{Co}_3\text{O}_4$ (c) / $\text{Co}$ (c), $\text{OH}^-$	-0.16	-1.00
$\text{CoOH}^+, \text{H}^+ / \text{Co}$ (c)	0.003	-0.04	$\text{Co(OH}_4^{2-} / \text{Co}$ (c), $\text{OH}^-$	-0.57	
$\text{Co}_4(\text{OH})_4^{4+}, \text{H}^+ / \text{Co}$ (c)	-0.06		$\text{Co(OH}_2$ (pt, bl) / $\text{Co}$ (c), $\text{OH}^-$	-0.703	
$\text{Co}^{2+} / \text{Co}$ (c)	-0.282	0.065	$\text{CoO}$ (c) / $\text{Co}$ (c), $\text{OH}^-$	-0.709	-1.269
			$\text{Co(OH}_2$ (pt, bl) / $\text{Co}$ (c), $\text{OH}^-$	-0.722	-1.04
			$\text{Co(OH}_2$ (c) / $\text{Co}$ (c), $\text{OH}^-$	-0.746	-1.02

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Rhodium 6-9</b>					
$\text{RhO}_3$ (c), $\text{H}^+ / \text{RhO}_2$ (c)	(1.8) <sup>a</sup>		$\text{RhO}_4^{2-} / \text{RhO}_2$ (c), $\text{OH}^-$	(0.9) <sup>a</sup>	
$\text{RhO}_3$ (c), $\text{H}^+$			$\text{RhO}_4^{2-} / \text{RhO}_2$ (pt), $\text{OH}^-$	(0.8) <sup>a</sup>	
$\text{Rh(OH}_2^{2+}$			$\text{RhO}_4^{2-} / \text{Rh(OH}_6^{2-}, \text{OH}^-$	(0.7) <sup>a</sup>	
$\text{Rh(OH}_2^{2+}, \text{H}^+ / \text{Rh}^{3+}$	(1.6)		$\text{RhO}_2$ (c) / $\text{Rh}_2\text{O}_3$ (c), $\text{OH}^-$	(0.4) (-1.0)	
$\text{RhO}_2$ (pt), $\text{H}^+ / \text{Rh}^{3+}$	(1.5)		$\text{RhO}_2$ (pt) /		(0.3)
$\text{RhO}_2$ (c), $\text{H}^+ / \text{Rh}^{3+}$	(1.3)	(-2.5)	$\text{Rh(OH}_3$ (pt, br), $\text{OH}^-$		
$\text{RhO}_2$ (c), $\text{H}^+ / \text{Rh}_2\text{O}_3$ (c)	(1.2)	(-0.2)	$\text{Rh(OH}_4^{2-} / \text{Rh(OH}_4^{+}, \text{OH}^-$	(0.3)	
$\text{RhO}_2$ (c), $\text{H}^+ / \text{RhOH}^{2+}$	(1.1)		$\text{Rh(OH}_4^{+} / \text{Rh}$ (c), $\text{OH}^-$	(0.12)	
$\text{Rh}^+$ / $\text{Rh}$ (c)	(1.0) <sup>a</sup>		$\text{Rh(OH}_3$ (pt, y) /		0.11
$\text{RhOH}^{2+}, \text{H}^+ / \text{Rh}$ (c)	0.83		$\text{Rh}$ (c), $\text{OH}^-$		
$\text{Rh}_2^{4+} / \text{Rh}$ (c)	(0.8)		$\text{RhO}_2$ (pt) /		(0.1)
$\text{Rh}_2\text{O}_3$ (c), $\text{H}^+ / \text{Rh}$ (c)	(0.77) <sup>b</sup>	(-0.41)	$\text{Rh(OH}_3$ (pt, y), $\text{OH}^-$		
$\text{Rh}^{3+} / \text{Rh}$ (c)	0.76	(0.4)	$\text{Rh(OH}_3$ (pt, br) /		(0.04)
$\text{Rh}^{3+} / \text{Rh}_2^{4+}$	(0.7)		$\text{Rh}$ (c), $\text{OH}^-$		
$\text{Rh}_2^{4+} / \text{Rh}$ *	(0.6) <sup>a</sup>		$\text{Rh}_2\text{O}_3$ (c) / $\text{Rh}$ (c), $\text{OH}^-$	(-0.06) <sup>b</sup>	(-1.25)
<b>Iridium 6, 7, 10</b>					
$\text{IrO}_3$ (c), $\text{H}^+ / \text{IrO}_2$ (c)	(1.5) <sup>a</sup>		$\text{IrO}_2(\text{OH})_2^{2-} / \text{IrO}_2$ (c), $\text{OH}^-$	(0.6) <sup>a</sup>	
$\text{IrO}_3$ (c), $\text{H}^+$	(1.3) <sup>a</sup>		$\text{IrO}_2(\text{OH})_2^{2-} / \text{IrO}_2$ (pt), $\text{OH}^-$	(0.5) <sup>a</sup>	
$\text{Ir(OH}_2^{2+}$			$\text{IrO}_2(\text{OH})_4^{2-} / \text{Ir(OH}_6^{2-}, \text{OH}^-$	(0.4) <sup>a</sup>	
$\text{Ir}^{3+} / \text{Ir}$ (c)	(1.0)		$\text{Ir(OH}_5^{3-} / \text{Ir}$ (c), $\text{OH}^-$	(0.2)	
$\text{Ir(OH}_2^{2+}, \text{H}^+ / \text{Ir}$ (c)	(0.84)		$\text{Ir(OH}_3$ (pt) / $\text{Ir}$ (c), $\text{OH}^-$	(0.2)	
$\text{Ir}_2\text{O}_3$ (c), $\text{H}^+ / \text{Ir}$ (c)	(0.8) <sup>a</sup>	(-0.42)	$\text{Ir(OH}_6^{2-} / \text{Ir}$ (c), $\text{OH}^-$	(0.01)	
$\text{IrO}_2$ (pt), $\text{H}^+ / \text{Ir}$ (c)	(0.79)		$\text{Ir}_2\text{O}_3$ (c) / $\text{Ir}$ (c), $\text{OH}^-$	(0.0) <sup>a</sup>	(-1.25)
$\text{IrO}_2$ (c), $\text{H}^+ / \text{Ir}$ (c)	0.73	(-0.36)	$\text{IrO}_2$ (pt) / $\text{Ir}$ (c), $\text{OH}^-$	(-0.04)	
$\text{Ir(OH}_2^{2+}, \text{H}^+ / \text{Ir}^{3+}$	(0.4)		$\text{IrO}_2$ (c) / $\text{Ir}$ (c), $\text{OH}^-$	-0.10	(-1.19)
$\text{IrO}_2$ (c), $\text{H}^+ / \text{Ir}^{3+}$	(0.3) <sup>a</sup>	(-0.2)	$\text{Ir}_2\text{O}_3$ (c) / $\text{Ir}$ (c), $\text{OH}^-$	(-0.5) <sup>a</sup>	(-1.0)
$\text{IrO}_2$ (pt), $\text{H}^+ / \text{Ir}^{3+}$	(0.2)		$\text{Ir(OH}_6^{2-} / \text{Ir(OH}_6^{3-}$	(-0.6)	
$\text{IrO}_2$ (c), $\text{H}^+ / \text{Ir}^{3+}$	(-0.1)		$\text{IrO}_2$ (pt) / $\text{Ir(OH}_3$ (pt), $\text{OH}^-$	(-0.7)	
<b>Nickel 6-9</b>					
$\text{Ni}^{3+} / \text{Ni}^{2+}$	(2.3)	(1.1)	$\text{NiOOH}$ (c, $\beta$ ) /	(1.0)	(-0.6)
$\text{NiOOH}$ (c, $\beta$ ), $\text{H}^+ / \text{Ni}^{2+}$	2.05	(-1.17)	$\text{Ni}_3\text{O}_4$ (c), $\text{OH}^-$		
$\text{Ni}_2\text{O}_3$ (c), $\text{H}^+ / \text{Ni}^{2+}$	(1.9)	(-1.4)	$\text{Ni}_2\text{O}_3$ (c) / $\text{Ni}_2\text{O}_3$ (c), $\text{OH}^-$	(0.9) <sup>a</sup>	(-1.2)
$\text{NiO}_2$ (c), $\text{H}^+ / \text{Ni}^{2+}$	(1.8) <sup>a</sup>	(-0.9)	$\text{Ni(OH}_4^{2-} /$	(0.7)	
$\text{NiO}_2$ (c), $\text{H}^+ / \text{Ni}_2\text{O}_3$ (c)	(1.7) <sup>a</sup>	(-0.4)	$\text{Ni(OH}_2$ (pt), $\text{OH}^-$		
$\text{NiOOH}$ (c, $\beta$ ), $\text{H}^+$	1.64	(-1.0)	$\text{Ni}_2\text{O}_3$ (c) / $\text{Ni}_2\text{O}_3$ (c), $\text{OH}^-$	(0.7) <sup>a</sup>	(-1.4)
$\text{Ni}_4\text{OH}_4^{4+}$			$\text{Ni}_4\text{OH}_4^{4+} /$	0.52	(-1.35)
$\text{Ni}_2\text{O}_2$ (c), $\text{H}^+$	(1.6) <sup>a</sup>	(-0.8)	$\text{Ni}_2\text{O}_2$ (c), $\text{OH}^-$		
$\text{Ni}_4\text{OH}_4^{4+}$			$\text{Ni}_2\text{O}_3$ (c) / $\text{Ni}_3\text{O}_4$ (c), $\text{OH}^-$	(0.5)	(-1.2)
$\text{Ni}_2\text{O}_2$ (c), $\text{H}^+$	(1.5) <sup>a</sup>	(-0.6)	$\text{Ni}_2\text{O}_2$ (c) / $\text{Ni}_2\text{O}_4^{2-}$	(0.5)	
$\text{Ni}_2\text{O}_3$ (c), $\text{H}^+$	(1.5)	(-1.2)	$\text{Ni}_2\text{O}_3$ (c) / $\text{Ni}_2\text{O}_2$ (c), $\text{OH}^-$	(0.3)	(-1.2)
$\text{Ni}_4\text{OH}_4^{4+}$			$\text{Ni}_3\text{O}_4$ (c) / $\text{Ni}_2\text{O}_2$ (c), $\text{OH}^-$	(0.3)	(-1.7)
$\text{Ni}_2\text{O}_2$ (c), $\text{H}^+ / \text{Ni}_2\text{O}_3$ (c)	(1.5) <sup>a</sup>	(-0.7)	$\text{Ni}_2\text{O}_2$ (c) / $\text{Ni}_2\text{O}_4^{2-}$	(0.2)	(-1.2)
$\text{Ni}_2\text{O}_3$ (c), $\text{H}^+$	(1.5)	(-1.1)	$\text{Ni}_2\text{O}_3$ (c) / $\text{Ni}_2\text{O}_2$ (c), $\text{OH}^-$	(0.3)	(-1.7)
$\text{Ni}_4\text{OH}_4^{4+}$			$\text{Ni}_3\text{O}_4$ (c) / $\text{Ni}_2\text{O}_2$ (c), $\text{OH}^-$	(0.2)	(-1.2)
$\text{Ni}_2\text{O}_2$ (c), $\text{H}^+ / \text{Ni}_2\text{O}_3$ (c)	1.47	(-0.9)	$\text{Ni}_2\text{O}_2$ (c) / $\text{Ni}_2\text{O}_4^{2-}$	(-0.56)	
$\text{Ni}_2\text{O}_3$ (c), $\text{H}^+ / \text{Ni}_2\text{O}_4^{2-}$	(1.3) <sup>a</sup>	(-2.9)	$\text{Ni}_2\text{O}_3$ (c) / $\text{Ni}_2\text{O}_2$ (c), $\text{OH}^-$	-0.688	-1.09
$\text{Ni}_2\text{O}_2$ (c), $\text{H}^+ / \text{Ni}_2\text{O}_4^{2-}$	0.035	(0.0)</td			

## STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

11

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Palladium<sup>6-10</sup></b>					
PdO <sub>3</sub> (c), H <sup>+</sup> / PdO <sub>2</sub> (c)	(2.0) <sup>a</sup>		PdO <sub>3</sub> (c) / PdO <sub>2</sub> (c), OH <sup>-</sup>	(1.2) <sup>a</sup>	
PdO <sub>3</sub> (c), H <sup>+</sup> / Pd(OH) <sub>2</sub> <sup>2+</sup>	(1.8) <sup>a</sup>		PdO <sub>4</sub> <sup>2-</sup> / PdO <sub>2</sub> (pt), OH <sup>-</sup>	(1.2) <sup>a</sup>	
Pd(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Pd <sup>2+</sup>	(1.54)		PdO <sub>4</sub> <sup>2-</sup> / Pd(OH) <sub>6</sub> <sup>2-</sup> , OH <sup>-</sup>	(1.1) <sup>a</sup>	
PdO <sub>2</sub> (c), H <sup>+</sup> / PdO (c)	1.47 (-0.4)		PdO <sub>2</sub> (c) / PdO (c), OH <sup>-</sup>	0.64 (-1.2)	
PdO <sub>2</sub> (pt), H <sup>+</sup> / PdO (pt)	(1.41) <sup>b</sup> (-0.4)		Pd(OH) <sub>6</sub> <sup>2-</sup> / Pd(OH) <sub>4</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.59)	
PdO <sub>2</sub> (c), H <sup>+</sup> / PdOH <sup>+</sup>	1.27		PdO <sub>2</sub> (pt) / PdO (pt), OH <sup>-</sup>	(0.58) <sup>b</sup> (-1.2)	
PdOH <sup>+</sup> , H <sup>+</sup> / Pd (c)	0.983		Pd(OH) <sub>4</sub> <sup>2-</sup> / Pd (c), OH <sup>-</sup>	(0.10)	
Pd <sup>2+</sup> / Pd (c)	0.915 0.12		PdO (pt) / Pd (c), OH <sup>-</sup>	0.069 -1.28	
PdO (pt), H <sup>+</sup> / Pd (c)	0.897 -0.45		PdO (c) / Pd (c), OH <sup>-</sup>	-0.04 -1.16	
PdO (c), H <sup>+</sup> / Pd (c)	0.79 -0.33				
<b>Platinum<sup>1, 6, 7, 9, 10</sup></b>					
PtO <sub>3</sub> (c), H <sup>+</sup> / PtO <sub>2</sub> (c)	(1.7) <sup>a</sup>		PtO <sub>3</sub> (c) / PtO <sub>2</sub> (c), OH <sup>-</sup>	(0.9) <sup>a</sup>	
PtO <sub>3</sub> (c), H <sup>+</sup> / Pt(OH) <sub>2</sub> <sup>2+</sup>	(1.5) <sup>a</sup>		PtO <sub>2</sub> (OH) <sub>4</sub> <sup>2-</sup> / PtO <sub>2</sub> (pt), OH <sup>-</sup>	(0.8) <sup>a</sup>	
PtOH <sup>+</sup> , H <sup>+</sup> / Pt (c)	(1.2)		PtO <sub>2</sub> (OH) <sub>4</sub> <sup>2-</sup> / Pt(OH) <sub>6</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.8) <sup>a</sup>	
Pt <sup>2+</sup> / Pt (c)	1.18 (-0.05)		Pt(OH) <sub>4</sub> <sup>2-</sup> / Pt (c), OH <sup>-</sup>	(0.20)	
Pt(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Pt (c)	(1.05)		PtO <sub>2</sub> (pt) / PtO (pt), OH <sup>-</sup>	0.18	
PtO <sub>2</sub> (pt), H <sup>+</sup> / PtO (pt)	1.01		Pt(OH) <sub>6</sub> <sup>2-</sup> / Pt (c), OH <sup>-</sup>	(0.18)	
PtO <sub>2</sub> (pt), H <sup>+</sup> / Pt (c)	1.00		PtO <sub>2</sub> (pt) / Pt (c), OH <sup>-</sup>	0.17	
PtO (pt), H <sup>+</sup> / Pt (c)	0.98 -0.53		PtO (pt) / Pt (c), OH <sup>-</sup>	0.15 -1.37	
PtO (c), H <sup>+</sup> / Pt (c)	(0.94) (-0.38)		Pt(OH) <sub>6</sub> <sup>2-</sup> / Pt(OH) <sub>4</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.15)	
PtO <sub>2</sub> (c), H <sup>+</sup> / Pt (c)	0.92 (-0.36)		PtO (c) / Pt (c), OH <sup>-</sup>	(0.11) (-1.22)	
Pt(OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Pt <sup>2+</sup>	(0.91)		PtO <sub>2</sub> (c) / Pt (c), OH <sup>-</sup>	0.09 (-1.19)	
PtO <sub>2</sub> (c), H <sup>+</sup> / PtO (c)	(0.91) (-0.33)		PtO <sub>2</sub> (c) / PtO (c), OH <sup>-</sup>	(0.08) (-1.17)	
PtO <sub>2</sub> (c), H <sup>+</sup> / PtOH <sup>+</sup>	(0.6)				
<b>Copper<sup>6-8</sup></b>					
Cu <sup>3+</sup> / Cu <sup>2+</sup>	(2.4) (1.5)		Cu(OH) <sub>4</sub> <sup>2-</sup> / Cu(OH) <sub>4</sub> <sup>2-</sup>	(0.8)	
Cu <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / Cu <sup>2+</sup>	(2.0) (-1.1)		Cu <sub>2</sub> O <sub>3</sub> (c) / CuO (c), OH <sup>-</sup>	(0.7) (-1.2)	
Cu <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / Cu <sub>2</sub> (OH) <sub>2</sub> <sup>2+</sup>	(1.7)		Cu <sub>2</sub> O <sub>3</sub> (c) / Cu(OH) <sub>2</sub> (c), OH <sup>-</sup>	(0.7) (-1.5)	
Cu <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / CuOH <sup>+</sup>	(1.5)		Cu(OH) <sub>4</sub> <sup>2-</sup> / Cu(OH) <sub>2</sub> <sup>2+</sup> , OH <sup>-</sup>	(-0.1)	
CuOH <sup>+</sup> / Cu <sub>2</sub> O (c)	0.676		Cu(OH) <sub>2</sub> (c) / Cu <sub>2</sub> O (c), OH <sup>-</sup>	-0.110 (-0.77)	
CuOH <sup>+</sup> , H <sup>+</sup> / Cu (c)	0.374		CuO (c) / Cu <sub>2</sub> O (c), OH <sup>-</sup>	-0.167 -1.109	
Cu <sup>+</sup> / Cu (c)	0.518 -0.754		Cu(OH) <sub>2</sub> <sup>2-</sup> / Cu (c), OH <sup>-</sup>	(-0.2)	
Cu <sub>2</sub> (OH) <sub>2</sub> <sup>2+</sup> / Cu <sub>2</sub> O (c)	0.513		Cu(OH) <sub>2</sub> (pt) / Cu (c), OH <sup>-</sup>	(-0.22) (-1.08)	
Cu <sub>2</sub> (OH) <sub>2</sub> <sup>2+</sup> , H <sup>+</sup> / Cu (c)	0.493		Cu(OH) <sub>2</sub> (c) / Cu (c), OH <sup>-</sup>	-0.233 (-1.03)	
Cu <sub>2</sub> O (c), H <sup>+</sup> / Cu (c)	0.473 -0.453		CuO (pt) / Cu (c), OH <sup>-</sup>	(-0.25)	
Cu <sup>2+</sup> / Cu (c)	0.339 0.011		CuO (c) / Cu (c), OH <sup>-</sup>	-0.271 -1.199	
Cu <sup>2+</sup> / Cu <sub>2</sub> O (c), H <sup>+</sup>	0.206 0.476		Cu <sub>2</sub> O (c) / Cu (c), OH <sup>-</sup>	-0.355 -1.289	
Cu <sup>2+</sup> / Cu <sup>+</sup>	0.161 0.776				
<b>Silver<sup>6-8</sup></b>					
Ag <sup>2+</sup> / Ag <sup>+</sup>	1.989 0.99		Ag <sub>2</sub> O <sub>3</sub> (c) / Ag <sub>2</sub> O <sub>2</sub> (c), OH <sup>-</sup>	0.887 -1.06	
Ag <sup>3+</sup> / Ag <sup>+</sup>	(1.9)		Ag(OH) <sub>4</sub> <sup>2-</sup> / Ag(OH) <sub>2</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.8)	
Ag <sub>2</sub> O <sub>2</sub> (c), H <sup>+</sup> / Ag <sup>+</sup>	1.802 0.19		Ag(OH) <sub>4</sub> <sup>2-</sup> / Ag(OH) <sub>2</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.75)	
Ag <sup>3+</sup> / Ag <sup>2+</sup>	(1.8)		Ag <sub>2</sub> O <sub>3</sub> (c) / Ag <sub>2</sub> O (c), OH <sup>-</sup>	0.744 -1.10	
Ag <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / Ag <sup>+</sup>	1.758 -0.02		Ag(OH) <sub>4</sub> <sup>2-</sup> / Ag(OH) <sub>4</sub> <sup>2-</sup>	(0.7)	
Ag <sub>2</sub> O <sub>2</sub> (c), H <sup>+</sup> / Ag <sub>2</sub> O <sub>2</sub> (c)	1.715 -0.23		Ag <sub>2</sub> O <sub>2</sub> (c) / Ag <sub>2</sub> O (c), OH <sup>-</sup>	0.602 -1.13	
Ag <sup>+</sup> / Ag (c)	0.7993 -0.989		Ag(OH) <sub>2</sub> <sup>2-</sup> / Ag (c), OH <sup>-</sup>	0.563	
			Ag <sub>2</sub> O (c) / Ag (c), OH <sup>-</sup>	0.343 -1.338	

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
<b>Gold<sup>1, 6-8, 10</sup></b>					
Au <sup>2+</sup> / Au <sup>+</sup>	(1.8) <sup>a</sup>		Au(OH) <sub>2</sub> <sup>2-</sup> / Au (c), OH <sup>-</sup>	(1.0)	
Au <sup>+</sup> / Au (c)	1.69 (-1.1)		Au(OH) <sub>4</sub> <sup>2-</sup> / Au (c), OH <sup>-</sup>	0.600 (-1.2)	
Au <sup>3+</sup> / Au (c)	(1.50)		Au <sub>2</sub> O <sub>3</sub> (pt) / Au (c), OH <sup>-</sup>	0.535 -1.279	
AuOH <sup>2+</sup> , H <sup>+</sup> / Au (c)	1.44		Au <sub>2</sub> O <sub>3</sub> (c) / Au (c), OH <sup>-</sup>	(0.52) -1.203	
Au <sup>3+</sup> / Au <sup>+</sup>	(1.41)		Au(OH) <sub>4</sub> <sup>2-</sup> / Au(OH) <sub>2</sub> <sup>2-</sup> , OH <sup>-</sup>	(0.4)	
Au <sub>2</sub> O <sub>3</sub> (pt), H <sup>+</sup> / Au (c)	1.363 -0.443		Au (c) / Au <sup>+</sup>	(-2.4) <sup>a</sup>	
Au <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / Au (c)	(1.35)	-0.367			
AuOH <sup>2+</sup> , H <sup>+</sup> / Au <sup>+</sup>	1.32				
Au <sub>2</sub> O <sub>3</sub> (pt), H <sup>+</sup> / Au <sup>+</sup>	1.20 (-0.1)				
Au <sub>2</sub> O <sub>3</sub> (c), H <sup>+</sup> / Au <sup>+</sup>	(1.18) (0.0)				
Au <sup>3+</sup> / Au <sup>2+</sup>	(1.0) <sup>a</sup>				
Au (c) / Au <sup>+</sup>	(-2.4) <sup>a</sup>				
<b>Zinc<sup>6-8</sup></b>					
ZnOH <sup>2+</sup> , H <sup>+</sup> / Zn (c)	-0.497 0.03		Zn(OH) <sub>4</sub> <sup>2-</sup> / Zn (c), OH <sup>-</sup>	-1.199	
Zn <sup>2+</sup> / Zn (c)	-0.762 0.119		Zn(OH) <sub>2</sub> (pt) / Zn (c), OH <sup>-</sup>	-1.222 (-1.04)	
			Zn(OH) <sub>2</sub> (c, t) / Zn (c), OH <sup>-</sup>	-1.249 -0.999	
			ZnO (c) / Zn (c), OH <sup>-</sup>	-1.260 -1.160	
<b>Cadmium<sup>1, 6-8</sup></b>					
CdOH <sup>2+</sup> , H <sup>+</sup> / Cd (c)	-0.104 0.02		Cd(OH) <sub>4</sub> <sup>2-</sup> / Cd (c), OH <sup>-</sup>	-0.658	
Cd <sup>2+</sup> / Cd (c)	(-0.2) <sup>a</sup>		CdO (c) / Cd (c), OH <sup>-</sup>	-0.783 -1.166	
Cd <sup>2+</sup> / Cd (c)	-0.402 -0.029		Cd(OH) <sub>2</sub> (pt) / Cd (c), OH <sup>-</sup>	-0.808 (-1.06)	
Cd <sup>2+</sup> / Cd <sup>2+</sup>	(-0.6) <sup>a</sup>		Cd(OH) <sub>2</sub> (c, t) / Cd (c), OH <sup>-</sup>	-0.826 -1.020	
<b>Mercury<sup>6-8</sup></b>					
Hg(OH) <sub>2</sub> , H <sup>+</sup> / Hg (liq)	1.034 -0.40		Hg(OH) <sub>3</sub> <sup>2-</sup> / Hg (liq), OH <sup>-</sup>	0.231	
Hg <sup>2+</sup> / Hg <sub>2</sub> <sup>2+</sup>	0.908 0.095		Hg(OH) <sub>2</sub> / Hg (liq), OH <sup>-</sup>	0.206 -1.24	
Hg <sup>2+</sup> / Hg (liq)	0.852 -0.116		HgO (pt) / Hg (liq), OH <sup>-</sup>	(0.11) (-1.17)	
Hg(OH) <sub>2</sub> , H <sup>+</sup> / Hg	0.830 -0.43		HgO (c, y) / Hg (liq), OH <sup>-</sup>	0.0983 -1.125	
Hg <sub>2</sub> <sup>2+</sup> / Hg (liq)	0.796 -0.327		HgO (c, r) / Hg (liq), OH <sup>-</sup>	0.0977 -1.1206	
Hg <sup>2+</sup> / Hg	0.648 -0.14				
Hg <sub>2</sub> <sup>2+</sup> / Hg	0.389 -0.38				
<b>Boron<sup>6-8</sup></b>					
B <sub>12</sub> (c), H <sup>+</sup> / B <sub>2</sub> H <sub>6</sub> (g)	-0.150 -0.296		B <sub>2</sub> H <sub>6</sub> (g) / BH <sub>4</sub> <sup>-</sup> , OH <sup>-</sup>	-0.782 -1.123	
B <sub>12</sub> (c), H <sup>+</sup> / BH <sub>4</sub> <sup>-</sup>	-0.237 -0.460		B <sub>12</sub> (c) / BH <sub>4</sub> <sup>-</sup> , OH <sup>-</sup>	-0.899 -1.129	
B <sub>2</sub> H <sub>6</sub> (g), H <sup>+</sup> / BH <sub>4</sub> <sup>-</sup>	-0.368 -0.705		B <sub>12</sub> (c) / B <sub>2</sub> H <sub>6</sub> (g), OH <sup>-</sup>	-0.978 -1.132	
B(OH) <sub>3</sub> (c), H <sup>+</sup> / BH <sub>4</sub> <sup>-</sup>	-0.481 -0.472		B(OH) <sub>4</sub> <sup>2-</sup> / BH <sub>4</sub> <sup>-</sup> , OH <sup>-</sup>	-1.241 -1.140	
B(OH) <sub>3</sub> (c), H <sup>+</sup> / BH <sub>4</sub> <sup>-</sup>	-0.482 -0.377		B(OH) <sub>4</sub> <sup>2-</sup> / B <sub>2</sub> H <sub>6</sub> (g), OH <sup>-</sup>	-1.394 -1.146	
B(OH) <sub>3</sub> (c), H <sup>+</sup> / B <sub>2</sub> H <sub>6</sub> (g)	-0.519 -0.394		B <sub>2</sub> (OH) <sub>6</sub> <sup>2-</sup> / B <sub>12</sub> (c), OH <sup>-</sup>	(-1.7)	
B(OH) <sub>3</sub> (c), H <sup>+</sup> /	-0.520 -0.267		B <sub>3</sub> O <sub>3</sub> (OH) <sub>4</sub> <sup>2-</sup> / B <sub>12</sub> (c), OH <sup>-</sup>	-1.763 -1.26	
B <sub>2</sub> H <sub>6</sub> (g)			B(OH) <sub>4</sub> <sup>2-</sup> / B <sub>12</sub> (c), OH <sup>-</sup>	-1.811 -1.160	
B <sub>2</sub> (OH) <sub>6</sub> <sup>2-</sup> / B <sub>12</sub> (c)	(-0.8) (-0.49)		B(OH) <sub>4</sub> <sup>2-</sup> / B <sub>2</sub> (OH) <sub>6</sub> <sup>2-</sup> , OH <sup>-</sup>	(-2.0)	
B <sub>2</sub> (OH) <sub>4</sub> (c), H <sup>+</sup> /	(-0.8) (-0.23)				
B <sub>12</sub> (c)					
B <sub>3</sub> O <sub>3</sub> (OH) <sub>4</sub> <sup>2-</sup> , H <sup>+</sup> /	-0.843 -0.33				
B <sub>12</sub> (c)					
B(OH) <sub>3</sub> (c), H <sup>+</sup> / B <sub>12</sub> (c)	-0.859 -0.492				
B(OH) <sub>3</sub> (c), H <sup>+</sup> / B <sub>12</sub> (c)	-0.890 -0.239				
B(OH) <sub>3</sub> (c), H <sup>+</sup> / B <sub>2</sub> (OH) <sub>4</sub>	(-1.1) (-0.50)				
B(OH) <sub>3</sub> (c), H <sup>+</sup> /	(-1.1) (-0.25)				
B <sub>2</sub> (OH) <sub>4</sub> (c)					

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH ~ 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH ~ 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Aluminum<sup>6-9</sup>

$\text{AlOH}_2^+$ , $\text{H}^+$ / $\text{Al}$ (c)	-1.579	0.28	$\text{Al(OH)}_3$ (pt) / $\text{Al}$ (c), $\text{OH}^-$	-2.31	-0.97
$\text{Al}_2(\text{OH})_2^{4+}$ , $\text{H}^+$ / $\text{Al}$ (c)	-1.60	0.32	$\text{Al(OH)}_4^-$ / $\text{Al}$ (c), $\text{OH}^-$	-2.328	-1.13
$\text{Al}^{3+}$ / $\text{Al}$ (c)	-1.677	0.533	$\text{Al}_2\text{O}_3$ (c, $\alpha$ ) / $\text{Al}$ (c), $\text{OH}^-$	-2.332	-1.140
$\text{Al}^{3+}$ , $\text{H}_2$ (g) / $\text{AlH}_4^-$	(-1.78) <sup>a</sup> (-0.21)		$\text{Al(OH)}_3$ (c, $\alpha$ ) / $\text{Al}$ (c), $\text{OH}^-$	-2.338	-0.927
$\text{Al}^{3+}$ , $\text{H}_2$ (g) / $\text{AlH}_3$ (c)	-1.838	-0.138	$\text{AlOOH}$ (c, $\alpha$ ) / $\text{Al}$ (c), $\text{OH}^-$	-2.371	-1.054

Gallium<sup>6-8</sup>

$\text{Ga}^+$ / $\text{Ga}$ (c)	(-0.2)		$\text{Ga}_2\text{O}$ (c) / $\text{Ga}$ (c), $\text{OH}^-$	(-0.9) <sup>a</sup> (-1.19)	
$\text{Ga}_2^{4+}$ / $\text{Ga}$ (c)	(-0.4)		$\text{Ga(OH)}_3$ (pt) / $\text{Ga}$ (c), $\text{OH}^-$	-1.242	-0.99
$\text{GaOH}_2^+$ , $\text{H}^+$ / $\text{Ga}$ (c)	-0.498		$\text{GaOOH}$ (c) / $\text{Ga}$ (c), $\text{OH}^-$	-1.320	(-1.08)
$\text{Ga}^{3+}$ / $\text{Ga}$ (c)	-0.549	0.61	$\text{Ga}_2\text{O}_3$ (c, $\beta$ ) / $\text{Ga}$ (c), $\text{OH}^-$	-1.323	-1.156
$\text{Ga}_2^{4+}$ / $\text{Ga}^+$	(-0.6)		$\text{Ga(OH)}_4^-$ / $\text{Ga}$ (c), $\text{OH}^-$	-1.326	
$\text{Ga}^{3+}$ / $\text{Ga}^+$	(-0.7)		$\text{GaOOH}$ (c) / $\text{Ga}_2\text{O}$ (c), $\text{OH}^-$	(-1.5) <sup>a</sup> (-1.03)	
$\text{Ga}^{3+}$ / $\text{Ga}_2^{4+}$	(-0.8)		$\text{Ga}_2\text{O}_3$ (c, $\beta$ ) / $\text{Ga}_2\text{O}$ (c), $\text{OH}^-$	(-1.5) <sup>a</sup> (-1.14)	
			$\text{Ga(OH)}_4^-$ / $\text{Ga}_2\text{O}$ (c), $\text{OH}^-$	(-1.5) <sup>a</sup>	

Indium<sup>6-9</sup>

$\text{In}^+$ / $\text{In}$ (c)	-0.126		$\text{In}_2\text{O}$ (c) / $\text{In}$ (c), $\text{OH}^-$	(-0.6) <sup>a</sup> (-1.12)	
$\text{InOH}_2^+$ , $\text{H}^+$ / $\text{In}$ (c)	-0.259		$\text{In(OH)}_3$ (pt) / $\text{In}$ (c), $\text{OH}^-$	-0.99	-0.95
$\text{In}_2^{4+}$ / $\text{In}$ (c)	-0.26		$\text{In(OH)}_4^-$ / $\text{In}$ (c), $\text{OH}^-$	-1.007	
$\text{In}^{3+}$ / $\text{In}$ (c)	-0.338	0.42	$\text{In}_2\text{O}_3$ (c) / $\text{In}$ (c), $\text{OH}^-$	-1.034	-1.131
$\text{In}_2^{4+}$ / $\text{In}^+$	-0.40		$\text{InOOH}$ (c) / $\text{In}$ (c), $\text{OH}^-$	-1.066	(-1.06)
$\text{In}^{3+}$ / $\text{In}^+$	-0.444		$\text{In(OH)}_4^-$ / $\text{In}_2\text{O}$ (c), $\text{OH}^-$	(-1.2) <sup>a</sup>	
$\text{In}^{3+}$ / $\text{In}_2^{4+}$	-0.49		$\text{In}_2\text{O}_3$ (c) / $\text{In}_2\text{O}$ (c), $\text{OH}^-$	(-1.2) <sup>a</sup> (-1.14)	
			$\text{InOOH}$ (c) / $\text{In}_2\text{O}$ (c), $\text{OH}^-$	(-1.3) <sup>a</sup> (-1.03)	

Thallium<sup>6-8</sup>

$\text{TiOH}_2^+$ , $\text{H}^+$ / $\text{Ti}^+$	1.299		$\text{Ti(OH)}_4^-$ / $\text{TiOH}$ (c), $\text{OH}^-$	0.099	
$\text{Ti}^{3+}$ / $\text{Ti}^+$	1.280	0.97	$\text{Ti(OH)}_4^-$ / $\text{TiOH}$ , $\text{OH}^-$	0.091	
$\text{TiOOH}$ (c), $\text{H}^+$ / $\text{Ti}^+$	1.225 (0.26)		$\text{TiOOH}$ (c) / $\text{TiOH}$ (c), $\text{OH}^-$	0.015 (-1.14)	
$\text{Ti}_2\text{O}_3$ (c), $\text{H}^+$ / $\text{Ti}^+$	1.165 (0.15)		$\text{Ti(OH)}_3$ (pt) / $\text{Ti}$ (c), $\text{OH}^-$	(-0.03) (-1.00)	
$\text{TiOH}_2^+$ , $\text{H}^+$ / $\text{Ti}$ (c)	0.754		$\text{Ti}_2\text{O}_3$ (c) / $\text{TiOH}$ (c), $\text{OH}^-$	-0.046 (-1.24)	
$\text{Ti}^{3+}$ / $\text{Ti}$ (c)	0.741	0.21	$\text{Ti(OH)}_4^-$ / $\text{Ti}$ (c), $\text{OH}^-$	-0.067	
$\text{TiOOH}$ (c), $\text{H}^+$ / $\text{Ti}$ (c)	0.705 (-0.26)		$\text{TiOOH}$ (c) / $\text{Ti}$ (c), $\text{OH}^-$	-0.123 (-1.10)	
$\text{Ti}_2\text{O}_3$ (c), $\text{H}^+$ / $\text{Ti}$ (c)	0.665 (-0.33)		$\text{Ti}_2\text{O}_3$ (c) / $\text{Ti}$ (c), $\text{OH}^-$	-0.163 (-1.17)	
$\text{Ti}^+$ / $\text{Ti}$ (c)	-0.336	-1.312	$\text{TiOH}$ / $\text{Ti}$ (c), $\text{OH}^-$	-0.382	
			$\text{TiOH}$ (c) / $\text{Ti}$ (c), $\text{OH}^-$	-0.399 -1.029	

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH ~ 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH ~ 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Carbon<sup>1, 6, 7</sup>

$\text{CH}_3\text{OH}, \text{H}^+$ / $\text{CH}_4$ (g)	0.583	-0.039	$\text{CH}_3\text{OH} / \text{CH}_4$ (g), $\text{OH}^-$	-0.245	-0.875
$\text{HCHO}_2, \text{H}^+$ / $\text{C}$ (c)	0.528	-0.77	$\text{CH}_2\text{O}$ / $\text{CH}_3\text{OH}, \text{OH}^-$	-0.591	-1.35
$\text{CO}$ (g), $\text{H}^+$ / $\text{C}$ (c)	0.5184	-1.3084	$\text{CHO}_2^-$ / $\text{C}$ (c), $\text{OH}^-$	-0.603	-1.65
$\text{CH}_3\text{OH}, \text{H}^+$ / $\text{CH}_4$	0.498	-0.370	$\text{C}_2\text{O}_4^{2-}$ / $\text{CHO}_2^-$ , $\text{OH}^-$	-0.683	-0.80
$\text{H}_2\text{CO}_3$ , $\text{H}^+$ / $\text{C}$ (c)	0.27	(-0.56)	$\text{C}$ (c), $\text{H}^+$ / $\text{CH}_4$ (g), $\text{OH}^-$	-0.6965	-1.0452
$\text{CH}_2\text{O}, \text{H}^+$ / $\text{CH}_3\text{OH}$	0.237	-0.51	$\text{CO}_3^{2-}$ / $\text{CH}_4$ (g), $\text{OH}^-$	-0.731	-1.135
$\text{CO}_2, \text{H}^+$ / $\text{C}$ (c)	0.229	-0.604	$\text{CO}_3^{2-}$ / $\text{C}$ (c), $\text{OH}^-$	-0.766	-1.225
$\text{CO}_2$ (g), $\text{H}^+$ / $\text{C}$ (c)	0.2073	-0.8530	$\text{CO}_3^{2-}$ / $\text{CHO}_2^-$ , $\text{OH}^-$	-0.930	-0.80
$\text{H}_2\text{C}_2\text{O}_4$ , $\text{H}^+$ / $\text{HCHO}_2$	0.204	(-0.12)	$\text{C}$ (c), $\text{H}^+$ / $\text{CH}_3\text{OH}, \text{OH}^-$	-1.148	-1.215
$\text{CO}_2$ (g), $\text{H}^+$ / $\text{CH}_4$ (g)	0.1694	-0.5311	$\text{CHO}_2^-$ / $\text{CH}_2\text{O}, \text{OH}^-$	-1.160	-1.52
$\text{C}$ (c), $\text{H}^+$ / $\text{CH}_4$ (g)	0.1315	-0.2092	$\text{CO}_3^{2-}$ / $\text{C}_2\text{O}_4^{2-}$ , $\text{OH}^-$	-1.176	-0.798
$\text{C}$ (c), $\text{H}^+$ / $\text{CH}_4$	0.089	-0.475			
$\text{H}_2\text{CO}_3, \text{H}^+$ / $\text{HCHO}_2$	0.01	(-0.35)			
$\text{HCHO}_2, \text{H}^+$ / $\text{CH}_2\text{O}$	-0.029	-0.63			
$\text{CO}_2, \text{H}^+$ / $\text{HCHO}_2$	-0.070	-0.44			
$\text{CO}_2$ (g), $\text{H}^+$ / $\text{CO}$ (g)	-0.1038	-0.3977			
$\text{CO}_2$ (g), $\text{H}^+$ / $\text{HCHO}_2$	-0.114	-0.94			
$\text{H}_2\text{CO}_3, \text{H}^+$ / $\text{H}_2\text{C}_2\text{O}_4$	-0.19	(-0.58)			
$\text{C}$ (c), $\text{H}^+$ / $\text{CH}_3\text{OH}$	-0.320	-0.379			
$\text{CO}_2, \text{H}^+$ / $\text{H}_2\text{C}_2\text{O}_4$	-0.345	(-0.77)			
$\text{CO}_2$ (g), $\text{H}^+$ / $\text{H}_2\text{C}_2\text{O}_4$	-0.432	(-1.76)			

Silicon<sup>6-8</sup>

$\text{Si}$ (c), $\text{H}^+$ / $\text{SiH}_4$ (g)	-0.147	-0.196	$\text{Si}$ (c) / $\text{SiH}_4$ (g), $\text{OH}^-$	-0.975	-1.032
$\text{SiO}_2$ (c, quartz), $\text{H}^+$ /	-0.569	-0.285	$\text{H}_2\text{SiO}_4^{2-}$ / $\text{SiH}_4$ (g), $\text{OH}^-$	-1.405	(-1.03)
$\text{SiH}_4$ (g)			$\text{SiO}$ (c) / $\text{Si}$ (c), $\text{OH}^-$	(-1.6) <sup>a</sup>	(-1.2)
$\text{SiO}$ (c), $\text{H}^+$ / $\text{Si}$ (c)	(-0.8) <sup>a</sup> (-0.4)		$\text{H}_2\text{SiO}_4^{2-}$ / $\text{Si}$ (c), $\text{OH}^-$	-1.820	-1.19
$\text{H}_4\text{SiO}_4$ , $\text{H}^+$ / $\text{Si}$ (c)	-0.931	-0.395	$\text{H}_2\text{SiO}_4^{2-}$ / $\text{SiO}$ (c), $\text{OH}^-$	-1.834	(-1.03)
$\text{SiO}_2$ (pt), $\text{H}^+$ / $\text{Si}$ (c)	-0.973	-0.40	$\text{H}_2\text{SiO}_4^{2-}$ / $\text{SiO}$ (c), $\text{OH}^-$	(-2.0) <sup>a</sup>	(-0.8)
$\text{SiO}_2$ (c, quartz), $\text{H}^+$ /	-0.990	-0.374			
$\text{Si}$ (c)					
$\text{SiO}_2$ (c, quartz), $\text{H}^+$ /	(-1.2) <sup>a</sup> (-0.3)				
$\text{Si}$ (c)					

Germanium<sup>6-8</sup>

$\text{Ge}(\text{OH})_2$ , $\text{H}^+$ / $\text{Ge}$ (c)	0.11		$\text{Ge}(\text{OH})_3^-$ / $\text{Ge}$ (c), $\text{OH}^-$	(-0.87)	
$\text{Ge}^{2+}$ / $\text{Ge}$ (c)	(0.1)		$\text{H}_3\text{GeO}_4^-$ / $\text{Ge}$ (c), $\text{OH}^-$	-0.936	
$\text{GeO}$ (pt, y), $\text{H}^+$ / $\text{Ge}$ (c)	0.04		$\text{H}_2\text{GeO}_4^{2-}$ / $\text{Ge}$ (c), $\text{OH}^-$	-0.957	
$\text{GeO}$ (c, br), $\text{H}^+$ / $\text{Ge}$ (c)	0.000	-0.41	$\text{H}_3\text{GeO}_4^-$ / $\text{Ge}(\text{OH})_3^-$ , $\text{OH}^-$	(-1.01)	
$\text{H}_4\text{GeO}_4$ , $\text{H}^+$ / $\text{Ge}$ (c)	-0.039	-0.429	$\text{H}_2\text{GeO}_4^{2-}$ / $\text{Ge}(\text{OH})_3^-$ , $\text{OH}^-$	(-1.05)	
$\text{GeO}_2$ (c, hex), $\text{H}^+$ /	-0.059	-0.377	$\text{Ge}$ (c) / $\text{GeH}_4$ (g), $\text{OH}^-$	-1.122	-1.031
$\text{Ge}(\text{c})$					
$\text{GeO}_2$ (c, tetr), $\text{H}^+$ /	-0.104	(-0.34)			
$\text{Ge}(\text{c})$					

## STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

13

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
Germanium -- Continued					
GeO <sub>2</sub> (c, hex), H <sup>+</sup> /	-0.118	-0.34			
GeO (c, br)					
H <sub>4</sub> GeO <sub>4</sub> , H <sup>+</sup> / GeO (pt, y)	-0.12				
H <sub>4</sub> GeO <sub>4</sub> , H <sup>+</sup> / Ge(OH) <sub>2</sub>	-0.19				
H <sub>4</sub> GeO <sub>4</sub> , H <sup>+</sup> / Ge <sup>2+</sup>	(-0.2)				
GeO <sub>2</sub> (c, hex), H <sup>+</sup> /	(-0.2)				
Ge <sup>2+</sup>					
GeO <sub>2</sub> (c, tetr), H <sup>+</sup> /	-0.207	(-0.26)			
GeO (c, br)					
Ge (c), H <sup>+</sup> / GeH <sub>4</sub> (g)	-0.294	-0.195			
GeO <sub>2</sub> (c, tetr), H <sup>+</sup> /	(-0.3)				
Ge <sup>2+</sup>					
Tin <sup>6-8</sup>					
Sn(OH) <sub>3</sub> <sup>+</sup> , H <sup>+</sup> / Sn <sup>2+</sup>	0.142		Sn(OH) <sub>3</sub> <sup>-</sup> / Sn (c), OH <sup>-</sup>	-0.892	
Sn(OH) <sub>2</sub> <sup>2-</sup> , H <sup>+</sup> / Sn <sup>2+</sup>	(0.10)		Sn(OH) <sub>2</sub> <sup>2-</sup> / SnO (pt), OH <sup>-</sup>	(-0.90)	
SnO <sub>2</sub> (pt, a), H <sup>+</sup> / Sn <sup>2+</sup>	(0.08) <sup>b</sup> (-0.46)		Sn(OH) <sub>2</sub> <sup>2-</sup> / Sn (c), OH <sup>-</sup>	(-0.91)	
SnO <sub>2</sub> (pt, p), H <sup>+</sup> / Sn <sup>2+</sup>	0.01		SnO (pt) / Sn (c), OH <sup>-</sup>	-0.917 -1.32	
SnOH <sup>+</sup> , H <sup>+</sup> / Sn (c)	-0.041		Sn(OH) <sub>2</sub> <sup>2-</sup> / Sn(OH) <sub>3</sub> <sup>-</sup> , OH <sup>-</sup>	(-0.93)	
SnO <sub>2</sub> (c), H <sup>+</sup> / Sn <sup>2+</sup>	-0.094	-0.31	SnO (c) / Sn (c), OH <sup>-</sup>	-0.930 -1.176	
SnO <sub>2</sub> (c), H <sup>+</sup> / Sn (c)	-0.117	-0.316	SnO <sub>2</sub> (c) / Sn (c), OH <sup>-</sup>	-0.945 -1.152	
Sn <sup>2+</sup> / Sn (c)	-0.141	0.32	SnO <sub>2</sub> (c) / SnO (c), OH <sup>-</sup>	-0.961 -1.129	
SnO <sub>2</sub> (c), H <sup>+</sup> / SnOH <sup>+</sup>	-0.194		Sn (c) / SnH <sub>4</sub> (g), OH <sup>-</sup>	-1.316 -1.057	
Sn (c), H <sup>+</sup> / SnH <sub>4</sub> (g)	-0.488	-0.221			

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
Nitrogen <sup>1, 6, 7</sup>					
H <sub>2</sub> N <sub>2</sub> O <sub>2</sub> , H <sup>+</sup> / N <sub>2</sub> (g)	(2.65) <sup>b</sup> (0.06)		N <sub>2</sub> O <sub>2</sub> <sup>2-</sup> / N <sub>2</sub> (g), OH <sup>-</sup>	(1.52) <sup>b</sup> (-0.65)	
HN <sub>3</sub> , H <sup>+</sup> / N <sub>2</sub> (g), NH <sub>4</sub> <sup>+</sup>	2.079	0.147	N <sub>2</sub> O (g) / N <sub>2</sub> (g), OH <sup>-</sup>	0.941 -1.297	
N <sub>2</sub> O (g), H <sup>+</sup> / N <sub>2</sub> (g)	1.769	-0.461	N <sub>2</sub> O (g) / NO <sub>2</sub> <sup>-</sup>	0.917 -1.712	
NO (g), H <sup>+</sup> / N <sub>2</sub> (g)	1.678	-0.9098	NO <sub>2</sub> (g) / NO <sub>2</sub> <sup>-</sup>	0.892 -0.801	
NO (g), H <sup>+</sup> / N <sub>2</sub> O (g)	1.587	-1.359	NO (g) / N <sub>2</sub> O (g), OH <sup>-</sup>	0.850 -1.7458	
HNO <sub>2</sub> , H <sup>+</sup> / N <sub>2</sub> (g)	1.447	-0.390	NO (g) / N <sub>2</sub> O (g), OH <sup>-</sup>	0.759 -2.195	
NH <sub>3</sub> OH <sup>+</sup> , H <sup>+</sup> / N <sub>2</sub> H <sub>5</sub> <sup>+</sup>	(1.40) <sup>b</sup> (-0.60)		N <sub>3</sub> <sup>-</sup> / N <sub>2</sub> (g), NH <sub>3</sub> , OH <sup>-</sup>	0.700 -0.921	
NH <sub>3</sub> OH <sup>+</sup> , H <sup>+</sup> / NH <sub>4</sub> <sup>+</sup>	(1.33) <sup>b</sup> (-0.44)		NH <sub>2</sub> OH / N <sub>2</sub> H <sub>4</sub> , OH <sup>-</sup>	(0.69) <sup>b</sup> (-1.68)	
N <sub>2</sub> H <sub>5</sub> <sup>+</sup> , H <sup>+</sup> / NH <sub>4</sub> <sup>+</sup>	1.250	-0.28	N <sub>2</sub> O <sub>2</sub> <sup>-</sup> / N <sub>2</sub> (g), OH <sup>-</sup>	0.406 -1.462	
NO <sub>3</sub> <sup>-</sup> , H <sup>+</sup> / N <sub>2</sub> (g)	1.244	-0.347	NH <sub>2</sub> OH / NH <sub>3</sub> , OH <sup>-</sup>	(0.40) <sup>b</sup> (-1.38)	
NO <sub>2</sub> (g), H <sup>+</sup> / HNO <sub>2</sub>	1.108	-1.582	NO <sub>3</sub> <sup>-</sup> / N <sub>2</sub> (g), OH <sup>-</sup>	0.251 -1.350	
N <sub>2</sub> O <sub>4</sub> (g), H <sup>+</sup> / HNO <sub>2</sub>	1.083	-0.671	NO (g) / N <sub>2</sub> O <sub>2</sub> <sup>2-</sup>	(0.18) <sup>b</sup> (-2.84)	
HNO <sub>2</sub> , H <sup>+</sup> / NO (g)	0.984	0.649	N <sub>2</sub> H <sub>4</sub> / NH <sub>3</sub> , OH <sup>-</sup>	0.111 -1.07	
NO <sub>3</sub> <sup>-</sup> , H <sup>+</sup> / NO (g)	0.955	0.028	NO <sub>3</sub> <sup>-</sup> / NO <sub>2</sub> <sup>-</sup> , OH <sup>-</sup>	0.017 -1.183	
NO <sub>3</sub> <sup>-</sup> , H <sup>+</sup> / HNO <sub>2</sub>	0.940	-0.282	NO <sub>3</sub> <sup>-</sup> / NH <sub>3</sub> , OH <sup>-</sup>	-0.119 -1.391	
NO <sub>3</sub> <sup>-</sup> , H <sup>+</sup> / NH <sub>4</sub> <sup>+</sup>	0.880	-0.448	NO <sub>3</sub> <sup>-</sup> / NO (g), OH <sup>-</sup>	-0.149 -1.086	
HNO <sub>2</sub> , H <sup>+</sup> / NH <sub>4</sub> <sup>+</sup>	0.860	-0.503	NO <sub>2</sub> <sup>-</sup> / N <sub>2</sub> O <sub>2</sub> <sup>2-</sup> , OH <sup>-</sup>	(-0.15) <sup>b</sup> (-1.87)	
HNO <sub>2</sub> , H <sup>+</sup> / H <sub>2</sub> N <sub>2</sub> O <sub>2</sub>	(0.85) <sup>b</sup> (-0.61)		NO <sub>2</sub> <sup>-</sup> / NH <sub>3</sub> , OH <sup>-</sup>	-0.165 -1.460	
NO <sub>3</sub> <sup>-</sup> , H <sup>+</sup> / N <sub>2</sub> O <sub>4</sub> (g)	0.798	0.107	NO <sub>2</sub> <sup>-</sup> / NO (g), OH <sup>-</sup>	0.481 -0.893	
NO <sub>3</sub> <sup>-</sup> , H <sup>+</sup> / NO <sub>2</sub> (g)	0.773	1.018	N <sub>2</sub> (g) / NH <sub>3</sub> , OH <sup>-</sup>	-0.736 -1.459	
NO (g), H <sup>+</sup> / H <sub>2</sub> N <sub>2</sub> O <sub>2</sub>	(0.71) <sup>b</sup> (-1.87)		N <sub>2</sub> O <sub>2</sub> <sup>2-</sup> / NH <sub>2</sub> OH, OH <sup>-</sup>	(-0.74) <sup>b</sup> (-1.13)	
H <sub>2</sub> N <sub>2</sub> O <sub>2</sub> , H <sup>+</sup> / NH <sub>3</sub> OH <sup>+</sup>	(0.41) <sup>b</sup> (-0.45)		NO <sub>3</sub> <sup>-</sup> / N <sub>2</sub> O <sub>4</sub> (g), OH <sup>-</sup>	-0.858 -1.565	
N <sub>2</sub> (g), H <sup>+</sup> / NH <sub>4</sub> <sup>+</sup>	0.274	-0.616	NO <sub>3</sub> <sup>-</sup> / NO <sub>2</sub> (g), OH <sup>-</sup>	-0.883 -0.654	
N <sub>2</sub> (g), H <sup>+</sup> / N <sub>2</sub> H <sub>5</sub> <sup>+</sup>	-0.214	-0.78	N <sub>2</sub> (g) / N <sub>2</sub> H <sub>4</sub> , OH <sup>-</sup>	-1.160 -1.65	
N <sub>2</sub> (g), H <sup>+</sup> / NH <sub>3</sub> OH <sup>+</sup>	(-1.83) <sup>b</sup> (-0.96)		N <sub>2</sub> (g) / NH <sub>2</sub> OH, OH <sup>-</sup>	(-3.01) <sup>b</sup> (-1.62)	
N <sub>2</sub> (g), H <sup>+</sup> / HN <sub>3</sub>	-3.334	-2.141	N <sub>2</sub> (g) / N <sub>3</sub> <sup>-</sup>	-3.608 -2.536	

 Phosphorus<sup>1, 6, 7</sup>

H <sub>4</sub> P <sub>2</sub> O <sub>6</sub> , H <sup>+</sup> / H <sub>2</sub> PHO <sub>3</sub>	(0.3)		P <sub>2</sub> O <sub>8</sub> <sup>4-</sup> / PHO <sub>3</sub> <sup>2-</sup> , OH <sup>-</sup>	(-0.4)
P <sub>2</sub> H <sub>4</sub> (liq), H <sup>+</sup> / PH <sub>3</sub> (g)	(0.06) <sup>b</sup> (0.48)		P <sub>2</sub> H <sub>4</sub> (liq) / PH <sub>3</sub> (g), OH <sup>-</sup>	(-0.77) <sup>b</sup> (-0.36)
P <sub>4</sub> (c, w), H <sup>+</sup> / PH <sub>3</sub> (g)	-0.046	-0.093	P <sub>4</sub> (c, w) / PH <sub>3</sub> (g), OH <sup>-</sup>	-0.874 -0.929
P <sub>4</sub> (c, r), H <sup>+</sup> / PH <sub>3</sub> (g)	-0.088	-0.030	P <sub>4</sub> (c, r) / PH <sub>3</sub> (g), OH <sup>-</sup>	-0.916 -0.866
P <sub>4</sub> (c, v), H <sup>+</sup> /	(-0.10) <sup>b</sup> (-0.38)		P <sub>4</sub> (c, v) / P <sub>2</sub> H <sub>4</sub> (liq), OH <sup>-</sup>	(-0.93) <sup>b</sup> (-1.22)
P <sub>2</sub> H <sub>4</sub> (liq)			P (c, r) / P <sub>2</sub> H <sub>4</sub> (liq), OH <sup>-</sup>	(-0.99) <sup>b</sup> (-1.12)
H <sub>2</sub> PH <sub>2</sub> O <sub>2</sub> , H <sup>+</sup> / PH <sub>3</sub> (g)	(-0.15) <sup>b</sup> (-0.13)		PO <sub>4</sub> <sup>3-</sup> / PHO <sub>3</sub> <sup>2-</sup> , OH <sup>-</sup>	(-1.14) <sup>b</sup> (-0.53)
P (c, r), H <sup>+</sup> / P <sub>2</sub> H <sub>4</sub> (liq)	(-0.16) <sup>b</sup> (-0.28)		PH <sub>2</sub> O <sub>2</sub> <sup>-</sup> / PH <sub>3</sub> (g), OH <sup>-</sup>	(-1.17) <sup>b</sup> (-1.07)
H <sub>2</sub> PH <sub>2</sub> O <sub>2</sub> , H <sup>+</sup> / PH <sub>3</sub> (g)	(-0.26) <sup>b</sup> (-0.21)		PO <sub>4</sub> <sup>3-</sup> / PH <sub>3</sub> (g), OH <sup>-</sup>	-1.247 -0.91
H <sub>3</sub> PO <sub>4</sub> , H <sup>+</sup> / PH <sub>3</sub> (g)	-0.269	-0.247	PHO <sub>3</sub> <sup>2-</sup> / PH <sub>3</sub> (g), OH <sup>-</sup>	(-1.28) <sup>b</sup> (-1.03)
H <sub>3</sub> PO <sub>4</sub> , H <sup>+</sup> / H <sub>2</sub> PHO <sub>3</sub>	(-0.30) <sup>b</sup> (-0.36)		PO <sub>4</sub> <sup>3-</sup> / P (c, r), OH <sup>-</sup>	-1.445 -0.93
H <sub>3</sub> PO <sub>4</sub> , H <sup>+</sup> / P (c, r)	(-0.33) <sup>b</sup> (-0.44)		PO <sub>4</sub> <sup>3-</sup> / P <sub>4</sub> (c, w), OH <sup>-</sup>	-1.470 -0.89
H <sub>3</sub> PO <sub>4</sub> , H <sup>+</sup> / P (c, r)	-0.377	-0.378	PHO <sub>3</sub> <sup>2-</sup> / PH <sub>2</sub> O <sub>2</sub> <sup>-</sup> , OH <sup>-</sup>	(-1.51) <sup>b</sup> (-0.95)
H <sub>3</sub> PO <sub>4</sub> , H <sup>+</sup> / P <sub>4</sub> (c, w)	-0.402	-0.340	PHO <sub>3</sub> <sup>2-</sup> / P (c, r), OH <sup>-</sup>	(-1.65) <sup>b</sup> (-1.20)
H <sub>2</sub> PHO <sub>3</sub> , H <sup>+</sup> / P (c, r)	(-0.43) <sup>b</sup> (-0.39)		PHO <sub>3</sub> <sup>2-</sup> / P <sub>4</sub> (c, w), OH <sup>-</sup>	(-1.69) <sup>b</sup> (-1.13)
H <sub>2</sub> PHO <sub>3</sub> , H <sup>+</sup> / P <sub>4</sub> (c, w)	(-0.45) <sup>b</sup> (-0.25)		PO <sub>4</sub> <sup>3-</sup> / P <sub>2</sub> O <sub>6</sub> <sup>4-</sup> , OH <sup>-</sup>	(-1.9)
H <sub>2</sub> PHO <sub>3</sub> , H <sup>+</sup> / P <sub>4</sub> (c, w)	(-0.47) <sup>b</sup> (-0.33)		PH <sub>2</sub> O <sub>2</sub> <sup>-</sup> / P (c, r), OH <sup>-</sup>	(-1.92) <sup>b</sup> (-1.70)
H <sub>2</sub> PHO <sub>3</sub> , H <sup>+</sup> / PH <sub>2</sub> O <sub>2</sub>	(-0.48) <sup>b</sup> (-0.37)		PH <sub>2</sub> O <sub>2</sub> <sup>-</sup> / P <sub>4</sub> (c, w), OH <sup>-</sup>	(-2.04) <sup>b</sup> (-1.51)
H <sub>3</sub> PO <sub>4</sub> , H <sup>+</sup> / H <sub>4</sub> P <sub>2</sub> O <sub>6</sub>	(-0.9)			

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$	$dE^\circ/dT$	Basic Solutions (pH = 13.996)	$E^\circ$	$dE^\circ/dT$
$\text{As}_2\text{O}_4(\text{c}), \text{H}^+ /$	(0.67) <sup>b</sup> (-0.33)		$\text{H}_2\text{AsO}_3^- / \text{As}(\text{c}), \text{OH}^-$	-0.674	-1.327
$\text{As}_4\text{O}_6(\text{c}, \text{cu})$			$\text{HAsO}_3^{2-} / \text{As}(\text{c}), \text{OH}^-$	-0.68	
$\text{As}_2\text{O}_4(\text{c}), \text{H}^+ / \text{H}_3\text{AsO}_3$	(0.63) <sup>b</sup> (0.05)		$\text{AsO}_4^{3-} / \text{As}(\text{c}), \text{OH}^-$	-0.702	-1.024
$\text{H}_3\text{AsO}_4, \text{H}^+ /$	0.595	-0.447	$\text{AsO}_4^{3-} / \text{HAsO}_3^{2-}, \text{OH}^-$	-0.74	
$\text{As}_4\text{O}_6(\text{c}, \text{cu})$			$\text{AsO}_4^{3-} / \text{H}_2\text{AsO}_3^{2-}, \text{OH}^-$	-0.745	-0.570
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{H}_3\text{AsO}_3$	0.575	-0.257	$\text{As}(\text{c}) / \text{AsH}_3(\text{g}), \text{OH}^-$	-1.066	-0.865
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{As}(\text{OH})_2^+$	0.566				
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{As}(\text{OH})_2^+$	(0.52) <sup>b</sup> (-0.56)				
$\text{As}(\text{OH})_2^+, \text{H}^+ / \text{As}(\text{c})$	0.253				
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{As}(\text{c})$	0.2475	-0.505			
$\text{As}_4\text{O}_6(\text{c}, \text{cu}), \text{H}^+ / \text{As}(\text{c})$	0.2340	-0.378			
$\text{As}(\text{c}), \text{H}^+ / \text{AsH}_3(\text{g})$	-0.238	-0.029			

**Arsenic<sup>6-8</sup>**

$\text{As}_2\text{O}_4(\text{c}), \text{H}^+ /$	(0.67) <sup>b</sup> (-0.33)		$\text{H}_2\text{AsO}_3^- / \text{As}(\text{c}), \text{OH}^-$	-0.674	-1.327
$\text{As}_4\text{O}_6(\text{c}, \text{cu})$			$\text{HAsO}_3^{2-} / \text{As}(\text{c}), \text{OH}^-$	-0.68	
$\text{As}_2\text{O}_4(\text{c}), \text{H}^+ / \text{H}_3\text{AsO}_3$	(0.63) <sup>b</sup> (0.05)		$\text{AsO}_4^{3-} / \text{As}(\text{c}), \text{OH}^-$	-0.702	-1.024
$\text{H}_3\text{AsO}_4, \text{H}^+ /$	0.595	-0.447	$\text{AsO}_4^{3-} / \text{HAsO}_3^{2-}, \text{OH}^-$	-0.74	
$\text{As}_4\text{O}_6(\text{c}, \text{cu})$			$\text{AsO}_4^{3-} / \text{H}_2\text{AsO}_3^{2-}, \text{OH}^-$	-0.745	-0.570
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{H}_3\text{AsO}_3$	0.575	-0.257	$\text{As}(\text{c}) / \text{AsH}_3(\text{g}), \text{OH}^-$	-1.066	-0.865
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{As}(\text{OH})_2^+$	0.566				
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{As}(\text{OH})_2^+$	(0.52) <sup>b</sup> (-0.56)				
$\text{As}(\text{OH})_2^+, \text{H}^+ / \text{As}(\text{c})$	0.253				
$\text{H}_3\text{AsO}_4, \text{H}^+ / \text{As}(\text{c})$	0.2475	-0.505			
$\text{As}_4\text{O}_6(\text{c}, \text{cu}), \text{H}^+ / \text{As}(\text{c})$	0.2340	-0.378			
$\text{As}(\text{c}), \text{H}^+ / \text{AsH}_3(\text{g})$	-0.238	-0.029			

**Antimony<sup>6-8, 10</sup>**

$\text{Sb}(\text{OH})_5, \text{H}^+ / \text{Sb}_2\text{O}_4(\text{c})$	0.98	0.18	$\text{Sb}_2\text{O}_4(\text{c}) /$	-0.437	-1.237
$\text{Sb}_2\text{O}_5(\text{c}), \text{H}^+ / \text{Sb}_2\text{O}_4(\text{c})$	0.76	-0.303	$\text{Sb}_4\text{O}_6(\text{c}, \text{cu}), \text{OH}^-$		
$\text{Sb}(\text{OH})_5, \text{H}^+ / \text{Sb}(\text{OH})_2^+$	0.57		$\text{Sb}_2\text{O}_4(\text{c}) /$	-0.477	-1.172
$\text{Sb}_2\text{O}_5(\text{c}), \text{H}^+ /$	0.57	-0.352	$\text{Sb}_2\text{O}_3(\text{c}, \text{rh}), \text{OH}^-$		
$\text{Sb}_4\text{O}_6(\text{c}, \text{cu})$			$\text{Sb}(\text{OH})_6^- /$	-0.48	
$\text{Sb}_2\text{O}_5(\text{c}), \text{H}^+ /$	0.55	-0.320	$\text{Sb}_4\text{O}_6(\text{c}, \text{cu}), \text{OH}^-$		
$\text{Sb}_2\text{O}_3(\text{c}, \text{rh})$			$\text{Sb}(\text{OH})_6^- /$	-0.50	
$\text{Sb}(\text{OH})_5, \text{H}^+ / \text{Sb}(\text{OH})_3$	0.54	-0.34	$\text{Sb}_2\text{O}_3(\text{c}, \text{rh}), \text{OH}^-$		
$\text{Sb}_2\text{O}_4(\text{c}), \text{H}^+ /$	0.391	-0.401	$\text{Sb}(\text{OH})_6^- / \text{Sb}_2\text{O}_4(\text{c}), \text{OH}^-$	-0.52	
$\text{Sb}_4\text{O}_6(\text{c}, \text{cu})$			$\text{Sb}(\text{OH})_6^- / (\text{Sb}(\text{OH})_4^-), \text{OH}^-$	-0.56	
$\text{Sb}_2\text{O}_4(\text{c}), \text{H}^+ /$	0.351	-0.336	$\text{Sb}(\text{OH})_4^- / \text{Sb}(\text{c}), \text{OH}^-$	-0.640	
$\text{Sb}_2\text{O}_3(\text{c}, \text{rh})$			$\text{Sb}_2\text{O}_3(\text{c}, \text{rh}) / \text{Sb}(\text{c}), \text{OH}^-$	-0.681	-1.205
$\text{Sb}(\text{OH})_5, \text{H}^+ / \text{Sb}(\text{c})$	0.231	-0.196	$\text{Sb}_4\text{O}_6(\text{c}, \text{cu}) / \text{Sb}(\text{c}), \text{OH}^-$	-0.694	-1.183
$\text{Sb}(\text{OH})_2^+, \text{H}^+ / \text{Sb}(\text{c})$	0.208		$\text{Sb}(\text{c}) / \text{SbH}_3(\text{g}), \text{OH}^-$	-1.338	-0.866
$\text{Sb}_2\text{O}_4(\text{c}), \text{H}^+ / \text{Sb}(\text{OH})_2^+$	0.169				
$\text{Sb}_2\text{O}_3(\text{c}, \text{rh}), \text{H}^+ / \text{Sb}(\text{c})$	0.147	-0.369			
$\text{Sb}_4\text{O}_6(\text{c}, \text{cu}), \text{H}^+ / \text{Sb}(\text{c})$	0.134	-0.347			
$\text{Sb}(\text{c}), \text{H}^+ / \text{SbH}_3(\text{g})$	-0.510	-0.030			

**Bismuth<sup>1, 6-8, 10</sup>**

$\text{Bi}(\text{OH})_5, \text{H}^+ / \text{Bi}_2\text{O}_4(\text{c})$	2.4		$\text{Bi}(\text{OH})_6^- / \text{Bi}_2\text{O}_4(\text{c}), \text{OH}^-$	(1.0)	
$\text{Bi}_2\text{O}_5(\text{c}), \text{H}^+ / \text{Bi}_2\text{O}_4(\text{c})$	(2.0)	(-0.3)	$\text{Bi}(\text{OH})_6^- / \text{BiOOH}(\text{c}), \text{OH}^-$	(0.8)	
$\text{Bi}(\text{OH})_5, \text{H}^+ /$	2.0		$\text{Bi}(\text{OH})_6^- / \text{Bi}_2\text{O}_3(\text{c}), \text{OH}^-$	(0.8)	
$\text{Bi}_6(\text{OH})_{12}^{6+}$			$\text{Bi}(\text{OH})_6^- / \text{Bi}(\text{OH})_3(\text{pt}), \text{OH}^-$	(0.7)	
$\text{Bi}(\text{OH})_5, \text{H}^+ / \text{Bi}^{3+}$	2.0		$\text{Bi}(\text{OH})_6^- / \text{Bi}(\text{OH})_4^-, \text{OH}^-$	(0.7)	
$\text{Bi}(\text{OH})_5, \text{H}^+ / \text{BiO}^{2+}$	2.0		$\text{Bi}_2\text{O}_4(\text{c}) / \text{Bi}_4\text{O}_7(\text{c}), \text{OH}^-$	0.62	(-1.15)
$\text{Bi}_2\text{O}_5(\text{c}), \text{H}^+ / \text{Bi}^{3+}$	(1.8)	(-1.1)	$\text{Bi}_2\text{O}_4(\text{c}) / \text{BiOOH}(\text{c}), \text{OH}^-$	0.59	(-1.38)
$\text{Bi}_2\text{O}_4(\text{c}), \text{H}^+ / \text{Bi}^{3+}$	1.59	(-2.0)	$\text{Bi}_4\text{O}_7(\text{c}) / \text{BiOOH}(\text{c}), \text{OH}^-$	0.56	(-1.62)
$\text{Bi}^+ / \text{Bi}(\text{c})$	(0.5) <sup>a</sup>		$\text{Bi}_2\text{O}_4(\text{c}) / \text{Bi}_2\text{O}_3(\text{c}), \text{OH}^-$	0.56	(-1.17)
$\text{BiO}^{2+}, \text{H}^+ / \text{Bi}(\text{c})$	0.329	(0.05)	$\text{Bi}_4\text{O}_7(\text{c}) / \text{Bi}_2\text{O}_3(\text{c}), \text{OH}^-$	0.51	(-1.19)
$\text{Bi}^{3+} / \text{Bi}(\text{c})$	0.308	(0.18)	$\text{Bi}(\text{OH})_4^- / \text{Bi}(\text{c}), \text{OH}^-$	-0.366	
$\text{Bi}_6(\text{OH})_{12}^{6+}, \text{H}^+ / \text{Bi}(\text{c})$	0.307		$\text{Bi}(\text{OH})_3(\text{pt}) / \text{Bi}(\text{c}), \text{OH}^-$	(-0.38) <sup>b</sup> (-1.04)	
$\text{Bi}^{3+} / \text{Bi}^+$	(0.2) <sup>a</sup>		$\text{Bi}_2\text{O}_3(\text{c}) / \text{Bi}(\text{c}), \text{OH}^-$	-0.452	-1.216
$\text{Bi}(\text{c}), \text{H}^+ / \text{BiH}_3(\text{g})$	(-0.8)	(-0.03)	$\text{BiOOH}(\text{c}) / \text{Bi}(\text{c}), \text{OH}^-$	-0.461	(-1.14)
$\text{Bi}(\text{c}), \text{H}^+ / \text{BiH}_3(\text{g}), \text{OH}^-$	(-1.6)	(-0.87)	$\text{Bi}(\text{c}) / \text{BiH}_3(\text{g}), \text{OH}^-$	(-1.6)	(-0.87)

**Oxygen<sup>6, 7, 9</sup>**

$\text{O}_2, \text{H}^+ /$	(3.3)	$\text{O}(\text{g}) / \text{OH}^-$	1.6021	-1.9844	
$\text{O}_2(\text{g}), \text{H}_2\text{O}(\text{liq})$		$\text{O}_3^- / \text{O}_2(\text{g}), \text{OH}^-$	(1.6)		
$\text{OH}, \text{H}^+ / \text{H}_2\text{O}(\text{liq})$	(2.56)	(-1.0)	$\text{O}^- / \text{OH}^-$	(1.60)	
$\text{O}(\text{g}), \text{H}^+ / \text{H}_2\text{O}(\text{liq})$	2.4301	-1.1484	$\text{O}_3(\text{g}) / \text{O}_2(\text{g}), \text{OH}^-$	1.247	-1.325
$\text{O}_3(\text{g}), \text{H}^+ /$	2.075	-0.489	$\text{O}_3(\text{g}) / \text{O}_3^-$	(0.9)	
$\text{O}_2(\text{g}), \text{H}_2\text{O}(\text{liq})$			$\text{HO}_2^- / \text{OH}^-$	0.867	-1.330
$\text{H}_2\text{O}_2, \text{H}^+ / \text{H}_2\text{O}(\text{liq})$	1.763	-0.698	$\text{O}_2(\text{g}) / \text{OH}^-$	0.4011	-1.6816
$\text{HO}_2, \text{H}^+ / \text{H}_2\text{O}_2$	1.44	(-0.7)	$\text{O}_2^- / \text{HO}_2^-, \text{OH}^-$	0.20	(-1.9)
$\text{O}_2, \text{H}^+ / \text{H}_2\text{O}_2(\text{liq})$	1.272	-0.601	$\text{HO}_2^- / \text{O}^-, \text{OH}^-$	(0.13)	
$\text{O}_2(\text{g}), \text{H}^+ / \text{H}_2\text{O}_2(\text{liq})$	1.2291	-0.8456	$\text{O}_2(\text{g}) / \text{HO}_2^-, \text{OH}^-$	-0.065	-2.033
$\text{H}_2\text{O}_2, \text{H}^+ / \text{OH}, \text{H}_2\text{O}(\text{liq})$	(0.96)	(-0.4)	$\text{O}_2(\text{g}) / \text{O}_2^-$	-0.33	(-2.2)
$\text{O}_3(\text{g}) / \text{O}_3^-$		(0.9)			
$\text{O}_2(\text{g}), \text{H}^+ / \text{H}_2\text{O}_2$	0.695	-0.993			
$\text{O}_2(\text{g}), \text{H}^+ / \text{HO}_2$	-0.05	(-1.3)			

**Sulfur<sup>6, 7, 10</sup>**

$\text{HS}_2\text{O}_4^+, \text{H}^+ / \text{HS}_2\text{O}_3^-$	(0.79)	(-0.50)	$\text{S}_4\text{O}_6^{2-} / \text{S}_2\text{O}_3^{2-}$	0.024	-1.31
$\text{SO}_2, \text{H}^+ / \text{S}_4\text{O}_6^{2-}$	0.539	-1.11	$\text{S}_2\text{O}_3^{2-} / \text{S}_2\text{O}_3^{2-}, \text{OH}^-$	-0.002	-1.27
$\text{HS}_2\text{O}_3^-, \text{H}^+ / \text{S}_8(\text{c})$	(0.47)	(-0.41)	$\text{S}_2\text{O}_3^{2-} / \text{S}_2\text{O}_3^{2-}$	(-0.16) <sup>b</sup> (-1.81)	
$\text{SO}_2, \text{H}^+ / \text{S}_8(\text{c})$	0.450	-0.652	$\text{S}_2^{2-} / \text{SH}^-, \text{OH}^-$	(-0.45) <sup>b</sup> (-0.71)	
$\text{SO}_2, \text{H}^+ / \text{HS}_2\text{O}_3^-$	(0.43)	(-0.89)	$\text{S}_8(\text{c}) / \text{SH}^-, \text{OH}^-$	-0.476	-0.934
$\text{S}_4\text{O}_6^{2-}, \text{H}^+ / \text{S}_8(\text{c})$	0.396	-0.38	$\text{S}_8(\text{c}) / \text{S}_2^{2-}$	(-0.30) <sup>b</sup> (-1.16)	
$\text{S}_2\text{O}_3^{2-}, \text{H}^+ / \text{S}_2\text{O}_2$	(0.37)	(0.90)	$\text{S}_2\text{O}_3^{2-} / \text{S}_2\text{O}_3^{2-}, \text{OH}^-$	-0.566	-1.06
$\text{SO}_4^{2-}, \text{H}^+ / \text{S}_8(\text{c})$	0.353	-0.173	$\text{S}_8(\text{c}) / \text{S}_2^{2-}$	-0.57	-1.34
$\text{HSO}_4^-, \text{H}^+ / \text{S}_8(\text{c})$	0.333	-0.366	$\text{S}_2\text{O}_3^{2-} / \text{SH}^-, \text{OH}^-$	-0.598	-1.13
$\text{SO}_4^{2-}, \text{H}^+ / \text{S}_4\text{O}_6^{2-}$	0.321	-0.03	$\text{S}_2\text{O}_3^{2-} / \text{S}_8(\text{c}), \text{OH}^-$	-0.614	-1.16
$\text{H}_2\text{S}_2, \text{H}^+ / \text{H}_2\text{S}(\text{g})$	0.174	0.224	$\text{SO}_4^{2-} / \text{S}_8(\text{c}), \text{OH}^-$	-0.751	-1.288
$\text{SO}_4^{2-}, \text{H}^+ / \text{S}_2\text{O}_2$	0.158	0.784	$\text{S}_2\text{O}_3^{2-} / \text{S}_8(\text{c}), \text{OH}^-$	-0.752	-1.40
$\text{S}_8(\text{c}), \text{H}^+ / \text{H}_2\text{S}$	0.144	-0.21	$\text{S}_2\text{O}_3^{2-} / \text{S}_4\text{O}_6^{2-}, \text{OH}^-$	-0.762	-0.98
$\text{S}_4\text{O}_6^{2-}, \text{H}^+ / \text{HS}_2\text{O}_3^-$	(0.10)	(-0.23)	$\text{SO}_4^{2-} / \text{S}_4\text{O}_6^{2-}, \text{OH}^-$	-0.862	-1.22
$\text{HSO}_4^-, \text{H}^+ / \text{S}_2\text{O}_$					

## STANDARD ELECTRODE POTENTIALS AND TEMPERATURE COEFFICIENTS IN WATER

15

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Tellurium <sup>1, 6-8</sup>					
$\text{H}_6\text{TeO}_5, \text{H}^+ / \text{TeO}_2(\text{c}, \alpha)$	(0.91) <sup>b</sup>	-0.12	$\text{H}_4\text{TeO}_6^{2-} / \text{TeO}_3^{2-}, \text{OH}^-$	(0.15) <sup>b</sup>	-0.63
$\text{H}_6\text{TeO}_5, \text{H}^+ / \text{Te(OH)}_3^+$	(0.85) <sup>b</sup>	-0.32	$\text{TeO}_3^{2-} / \text{Te}(\text{c}), \text{OH}^-$	-0.47	-1.39
$\text{Te}(\text{OH})_3^+, \text{H}^+ / \text{Te}(\text{c})$	0.558	-0.294	$\text{Te}(\text{c}) / \text{Te}_2^{2-}$	-0.84	
$\text{TeO}_2(\text{c}, \alpha), \text{H}^+ / \text{Te}(\text{c})$	0.529	-0.391	$\text{Te}(\text{c}) / \text{Te}^{2-}$	-0.90	(-1.0)
$\text{Te}(\text{c}), \text{H}^+ / \text{H}_2\text{Te}(\text{g})$	-0.44	0.26	$\text{Te}_2^{2-} / \text{Te}^{2-}$	-0.96	
$\text{Te}(\text{c}), \text{H}^+ / \text{H}_2\text{Te}$	-0.46	(-0.16)			

Polonium <sup>6, 7</sup>					
$\text{H}_6\text{PoO}_6, \text{H}^+ / \text{PoO}_2(\text{c}, \alpha)$	(2.3) <sup>a</sup>		$\text{H}_4\text{PoO}_6^{2-} / \text{PoO}_3^{2-}, \text{OH}^-$	(1.4) <sup>a</sup>	
$\text{H}_6\text{PoO}_6, \text{H}^+ / \text{Po(OH)}_3^+$	(2.2) <sup>a</sup>		$\text{PoO}(\text{c}) / \text{Po}(\text{c}), \text{OH}^-$	(-0.1)	
$\text{H}_6\text{PoO}_6, \text{H}^+ / \text{Po}^{4+}$	(2.1) <sup>a</sup>		$\text{PoO}_3^{2-} / \text{Po}(\text{c}), \text{OH}^-$	(-0.2)	
$\text{Po}^{4+} / \text{Po}^{2+}$	(0.9)		$\text{PoO}_3^{2-} / \text{PoO}(\text{c}), \text{OH}^-$	(-0.3)	
$\text{Po}(\text{OH})_3^+, \text{H}^+ / \text{Po}^{2+}$	(0.8)		$\text{Po}(\text{c}) / \text{Po}_2^{2-}$	(-1.0)	
$\text{Po}^{4+} / \text{Po}(\text{c})$	0.76		$\text{Po}(\text{c}) / \text{Po}^{2-}$	(-1.1)	(-0.9)
$\text{PoO}_2(\text{c}, \alpha), \text{H}^+ / \text{Po}(\text{c})$	(0.7)		$\text{Po}_2^{2-} / \text{Po}^{2-}$	(-1.1)	
$\text{PoO}_2(\text{c}, \alpha), \text{H}^+ / \text{Po}(\text{c})$	(0.7)	(-0.37)			
$\text{Po}^{2+} / \text{Po}(\text{c})$	(0.6)				
$\text{Po}(\text{c}), \text{H}^+ / \text{H}_2\text{Po}(\text{g})$	(-0.7)	(0.26)			
$\text{Po}(\text{c}), \text{H}^+ / \text{H}_2\text{Po}$	(-0.7)				

Fluorine <sup>6, 7</sup>					
$\text{OF}_2(\text{g}), \text{H}^+ / \text{O}_2(\text{g}), \text{HF}$	3.294	-0.508	$\text{OF}_2(\text{g}) / \text{O}_2(\text{g}), \text{F}^-$	3.107	-1.570
$\text{OF}_2(\text{g}) / \text{O}_2(\text{g}), \text{F}^-$	3.107	-1.570	$\text{F}_2(\text{g}) / \text{F}^-$	2.890	-1.870
$\text{F}_2(\text{g}), \text{H}^+ / \text{HF}$	3.077	-0.808	$\text{OF}_2(\text{g}) / \text{F}^-, \text{OH}^-$	1.754	-1.626
$\text{F}_2(\text{g}), \text{H}^+ / \text{HF}_2$	2.996	-1.248	$\text{OF}_2(\text{g}) / \text{F}_2(\text{g}), \text{OH}^-$	0.618	-1.382
$\text{F}_2(\text{g}) / \text{F}^-$	2.890	-1.870			
$\text{OF}_2(\text{g}), \text{H}^+ / \text{HF}$	2.262	-0.677			
$\text{OF}_2(\text{g}), \text{H}^+ / \text{F}^-$	2.168	-1.208			
$\text{OF}_2(\text{g}), \text{H}^+ / \text{F}_2(\text{g})$	1.446	-0.546			

Chlorine <sup>6, 7</sup>					
$\text{HClO}_2, \text{H}^+ / \text{HClO}$	1.674	-0.55	$\text{Cl}_2(\text{g}) / \text{Cl}^-$	1.3604	-1.248
$\text{HClO}, \text{H}^+ / \text{Cl}_2(\text{g})$	1.630	-0.27	$\text{ClO}_2 / \text{ClO}_2^-$	1.068	-1.335
$\text{HClO}, \text{H}^+ / \text{Cl}_2$	1.594	-0.80	$\text{ClO}^- / \text{Cl}^-, \text{OH}^-$	0.890	-1.08
$\text{ClO}_3^-, \text{H}^+ / \text{Cl}_2(\text{g})$	1.458	-0.347	$\text{ClO}_2^- / \text{Cl}^-, \text{OH}^-$	0.786	-1.267
$\text{Cl}_3^- / \text{Cl}^-$	1.416	(-0.8)	$\text{ClO}_2^- / \text{ClO}^-, \text{OH}^-$	0.681	-1.46
$\text{ClO}_3^-, \text{H}^+ / \text{HClO}$	1.415	-0.37	$\text{ClO}_3^- / \text{Cl}^-, \text{OH}^-$	0.614	-1.333
$\text{Cl}_2 / \text{Cl}^-$	1.396	-0.72	$\text{ClO}_4^- / \text{Cl}^-, \text{OH}^-$	0.560	-1.313
$\text{ClO}_4^-, \text{H}^+ / \text{Cl}_2(\text{g})$	1.392	-0.367	$\text{ClO}_3^- / \text{ClO}^-, \text{OH}^-$	0.476	-1.46
$\text{Cl}_2(\text{g}) / \text{Cl}^-$	1.3604	-1.248	$\text{ClO}_3^- / \text{Cl}_2(\text{g}), \text{OH}^-$	0.465	-1.350
$\text{Cl}_2 / \text{Cl}_3^-$	1.356	(-0.6)	$\text{ClO}_4^- / \text{Cl}_2(\text{g}), \text{OH}^-$	0.446	-1.322
$\text{Cl}_2(\text{g}) / \text{Cl}_3^-$	1.249	(-2.2)	$\text{ClO}^- / \text{Cl}_2(\text{g}), \text{OH}^-$	0.420	-0.90
$\text{ClO}_4^-, \text{H}^+ / \text{ClO}_3^-$	1.226	-0.416	$\text{ClO}_4^- / \text{ClO}_3^-, \text{OH}^-$	0.398	-1.252
$\text{ClO}_2, \text{H}^+ / \text{HClO}_2$	1.184	-0.433	$\text{ClO}_3^- / \text{ClO}_2^-, \text{OH}^-$	0.271	-1.466
$\text{ClO}_3^-, \text{H}^+ / \text{HClO}_2$	1.157	-0.180	$\text{ClO}_3^- / \text{ClO}_2^-, \text{OH}^-$	-0.526	-1.598
$\text{ClO}_3^-, \text{H}^+ / \text{ClO}_2$	1.130	0.074			

Table I. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K -- Continued

Acid Solutions (pH = 0.000)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^\circ$ (V)	$dE^\circ/dT$ (mV/K)
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Bromine <sup>6, 7</sup>					
$\text{BrO}_4^-, \text{H}^+ / \text{BrO}_3^-$	1.745	-0.511	$\text{Br}_2(\text{liq}) / \text{Br}^-$	1.078	-0.611
$\text{HBrO}, \text{H}^+ / \text{Br}_2(\text{liq})$	1.604	-0.63	$\text{BrO}_4^-, \text{BrO}_3^-, \text{OH}^-$	0.917	-1.347
$\text{HBrO}, \text{H}^+ / \text{Br}_2(\text{g})$	1.588	-0.15	$\text{BrO}^- / \text{Br}^-, \text{OH}^-$	0.766	-0.94
$\text{HBrO}, \text{H}^+ / \text{Br}_2$	1.584	-0.75	$\text{BrO}_3^- / \text{Br}^-, \text{OH}^-$	0.613	-1.287
$\text{BrO}_3^-, \text{H}^+ / \text{Br}_2(\text{liq})$	1.513	-0.419	$\text{BrO}_3^- / \text{BrO}^-, \text{OH}^-$	0.536	-1.46
$\text{BrO}_3^-, \text{H}^+ / \text{Br}_2(\text{g})$	1.510	-0.323	$\text{BrO}_3^- / \text{Br}_2(\text{liq}), \text{OH}^-$	0.520	-1.422
$\text{BrO}_3^-, \text{H}^+ / \text{HBrO}$	1.491	-0.37	$\text{BrO}^- / \text{Br}_2(\text{liq}), \text{OH}^-$	0.455	-1.27
$\text{Br}_2 / \text{Br}_3^-$	1.171	-0.472			
$\text{Br}_2(\text{g}) / \text{Br}_3^-$	1.159	-2.258			
$\text{Br}_2(\text{liq}) / \text{Br}_3^-$	1.110	-0.810			
$\text{Br}_2 / \text{Br}^-$	1.098	-0.499			
$\text{Br}_2(\text{g}) / \text{Br}^-$	1.094	-1.094			
$\text{Br}_2(\text{liq}) / \text{Br}^-$	1.078	-0.611			
$\text{Br}_3^- / \text{Br}^-$	1.062	-0.512			
Iodine <sup>6, 7, 10</sup>					
$\text{IO}_4^-, \text{H}^+ / \text{IO}_3^-$	1.589	-0.85	$\text{IO}_4^-, \text{IO}_3^-, \text{OH}^-$	0.761	-1.69
$\text{H}_5\text{IO}_6, \text{H}^+ / \text{HIO}_3$	1.567	-0.12	$\text{H}_3\text{IO}_6^{2-} / \text{IO}_3^-, \text{OH}^-$	0.589	-0.72
$\text{HIO}, \text{H}^+ / \text{I}_2(\text{c})$	1.430	-0.339	$\text{I}_2(\text{c}) / \text{I}^-$	0.535	-0.125
$\text{I}^+ / \text{I}_2(\text{c})$	1.35		$\text{IO}^- / \text{I}^-, \text{OH}^-$	0.469	-0.546
$\text{HIO}, \text{H}^+ / \text{I}_2$	1.345	-0.230	$\text{IO}^- / \text{I}_2(\text{c}), \text{OH}^-$	0.403	-0.966
$\text{IO}_3^- / \text{I}_2(\text{c})$	1.210	-0.367	$\text{IO}_3^- / \text{I}^-, \text{OH}^-$	0.269	-1.163
$\text{HIO}_3, \text{H}^+ / \text{HAI}_2$	1.200	-0.468	$\text{IO}_3^- / \text{I}_2(\text{c}), \text{OH}^-$	0.216	-1.370
$\text{HIO}_3, \text{H}^+ / \text{I}^+$	1.16		$\text{IO}_3^- / \text{IO}^-, \text{OH}^-$	0.169	-1.471
$\text{IO}_3^-, \text{H}^+ / \text{HIO}$	1.154	-0.374			
$\text{I}_2 / \text{I}_3^-$	0.789	-0.329			
$\text{I}_2 / \text{I}^-$	0.620	-0.234			
$\text{I}_3^- / \text{I}^-$	0.535	-0.186			
$\text{I}_2(\text{c}) / \text{I}^-$	0.535	-0.125			
$\text{I}_2(\text{c}) / \text{I}_3^-$	0.534	-0.002			

Astatine <sup>9</sup>					
$\text{AtO}_4^-, \text{H}^+ / \text{AtO}_3^-$	(2.7) <sup>a</sup>		$\text{AtO}_4^-, \text{AtO}_3^-, \text{OH}^-$	(1.9) <sup>a</sup>	
$\text{H}_5\text{AtO}_6, \text{H}^+ / \text{HAtO}_3$	(2.7) <sup>a</sup>		$\text{H}_3\text{AtO}_6^{2-} / \text{AtO}_3^-, \text{OH}^-$	(1.8) <sup>a</sup>	
$\text{AtO}_3^-, \text{H}^+ / \text{HAtO}$	(1.5)		$\text{AtO}_3^-, \text{At}^-, \text{OH}^-$	(0.5)	
$\text{HAtO}_3, \text{H}^+ / \text{At}^-$	1.5		$\text{AtO}^- / \text{At}(\text{c}), \text{OH}^-$	(0.3)	
$\text{HAtO}, \text{H}^+ / \text{At}_2$	(1.1)		$\text{At}(\text{c}) / \text{At}^-$	0.2	(0.0)
$\text{At}^+ / \text{At}(\text{c})$	1.0				
$\text{At}_2 / \text{At}_3^-$	(0.5)				
$\text{At}_2 / \text{At}^-$	(0.3)	(-0.1)			
$\text{At}_3^- / \text{At}^-$	(0.2)				
$\text{At}(\text{c}) / \text{At}^-$	0.2	(0.0)			
$\text{At}(\text{c}) / \text{At}_3^-$	(0.2)				

Table 1. Standard Electrode Potentials and Temperature Coefficients in Water at 298.15 K Continued

Acid Solutions (pH = 0.000)	$E^{\circ}$ (V)	$dE^{\circ}/dT$ (mV/K)	Basic Solutions (pH = 13.996)	$E^{\circ}$ (V)	$dE^{\circ}$ (mV)
<b>Krypton</b>					
$\text{KrO}_2, \text{H}^+ / \text{Kr(g)}$	(2.5) <sup>a</sup>		$\text{KrO}_4 / \text{KrO}_3\text{OH}^-, \text{OH}^-$	(1.8) <sup>a</sup>	
$\text{KrO}_4, \text{H}^+ / \text{KrO}_3$	(2.5) <sup>a</sup>		$\text{KrO} / \text{Kr(g)}, \text{OH}^-$	(1.7) <sup>a</sup>	
$\text{KrO}_3, \text{H}^+ / \text{Kr(g)}$	(2.4) <sup>a</sup>		$\text{KrO}_3\text{OH}^- / \text{Kr(g)}, \text{OH}^-$	(1.5) <sup>a</sup>	
$\text{KrO}_3, \text{H}^+ / \text{KrO}$	(2.3) <sup>a</sup>		$\text{KrO}_3\text{OH}^- / \text{KrO}, \text{OH}^-$	(1.4) <sup>a</sup>	
<b>Xenon 6, 7, 9</b>					
$\text{XeO}_6, \text{H}^+ / \text{XeO}_3$	2.38	(0.0)	$\text{XeO} / \text{Xe(g)}, \text{OH}^-$	(1.5) <sup>a</sup>	
$\text{XeO}, \text{H}^+ / \text{Xe(g)}$	(2.3) <sup>a</sup>		$\text{XeO}_3\text{OH}^- / \text{Xe(g)}, \text{OH}^-$	1.24	
$\text{XeO}_3, \text{H}^+ / \text{Xe(g)}$	2.10	0.34	$\text{HXeO}_6^{3-} / \text{Xe(g)}, \text{OH}^-$	(1.17)	
$\text{XeO}_3, \text{H}^+ / \text{XeO}$	(2.0) <sup>a</sup>		$\text{XeO}_3\text{OH}^- / \text{XeO}, \text{OH}^-$	(1.1) <sup>a</sup>	
			$\text{HXeO}_6^{3-} / \text{XeO}_3\text{OH}^-, \text{OH}^-$	(0.95)	
<b>Radon</b>					
$\text{Rn}_4\text{RnO}_6, \text{H}^+ / \text{RnO}_3$	(3.4) <sup>a</sup>		$\text{HRnO}_6^{3-} / \text{RnO}_3\text{OH}^-, \text{OH}^-$	(2.1) <sup>a</sup>	
$\text{RnO}_3, \text{H}^+ / \text{Rn}^{2+}$	(2.4) <sup>a</sup>		$\text{RnO}_3\text{OH}^- / \text{RnO}, \text{OH}^-$	(1.5) <sup>a</sup>	
$\text{Rn}^{2+} / \text{Rn(g)}$	(2.0) <sup>a</sup>		$\text{RnO} / \text{Rn(g)}, \text{OH}^-$	(1.2) <sup>a</sup>	

**Notes to Table 1:**<sup>a</sup>This half-reaction involves at least one doubtful chemical species (See text).<sup>b</sup> $\Delta H^{\circ}$  is experimentally known for this half-reaction (See text).

positive than when calculated for unit activity  $\text{OH}^-$  (aq). Two of these half-reactions have been included in the master listing of  $E^{\circ}$  values at the end of Ref. 9 (pp. 787-802) and are inconsistent with the other  $E^{\circ}$  values found there. They are  $E^{\circ}[\text{VO}_4^{3-}/\text{V(c)}, \text{OH}^-] = 0.120$  V (Table 1: - 1.222 V) and  $E^{\circ}[\text{VO(c)}/\text{V(c)}, \text{OH}^-] = - 0.82$  V (Table 1: - 1.693 V).  $E^{\circ}[\text{CrO}_4^{2-}/\text{Cr(OH)}_4^-, \text{OH}^-]$  has been given (p. 461) as - 0.72 V (Table 1: - 0.14 V), which actually applies to  $E^{\circ}[\text{CrO}_4^{2-}/\text{Cr(c)}, \text{OH}^-]$ . The incorrectly assigned value for this important half-reaction has also been included in the master listing.

It is hoped that the many individuals connected with Ref. 9 will understand that the above discussion has been given only because it is necessary for the justification of the present work.

**3. Limitations and Scope: Formula Writing**

Table 1 contains standard electrode potentials and temperature coefficients in water at 298.15 K for nearly 1700 half-reactions at  $p\text{H} = 0.000$  and  $p\text{H} = 13.996$ . The data allow the calculation of the thermodynamic changes and equilibrium constants associated with about 1.4 million complete cell reactions.

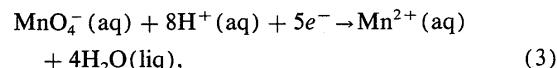
In order to keep this report to a manageable size, it has been necessary to consider only chemical species which involve hydrogen, oxygen, and at most one other element. Chemical species containing O-O bonds have not been considered, except for  $\text{H}_2\text{O}_2$ ,  $\text{HO}_2^-$ ,  $\text{HO}_2$ ,  $\text{O}_2^-$  and  $\text{O}_3^-$ . Physical

states have been indicated by (c) = pure crystalline solid, (pt) = hydrous precipitate (amorphous solid with variable water content), (liq) = pure liquid, (g) = ideal gas at one atmosphere fugacity, and unspecified = ideal aqueous solute at one molal activity. A few crystalline solids have been further identified by the crystal system, thus cu = cubic, hex = hexagonal, rh = orthorhombic, and tetr = tetragonal. Also, the colors have been specified for a few substances, thus r = red, pk = pink, y = yellow, bl = blue, br = brown, and w = white.

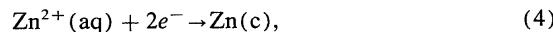
An attempt has been made to represent realistically the chemical formulas of aqueous species in Table 1; thus  $\text{S}^{\text{IV}}$  and  $\text{Se}^{\text{VI}}$  in acid solution have been written as  $\text{SO}_2$  and  $\text{H}_2\text{SeO}_3$ , respectively, and  $\text{Ru}^{\text{VI}}$  and  $\text{Os}^{\text{VI}}$  in basic solution have been written as  $\text{RuO}_4^{2-}$  and  $\text{OsO}_2(\text{OH})_4^{2-}$ , respectively. However, attached water molecules have been omitted from chemical formulas; hence  $\text{Al}^{3+}$ ,  $\text{H}^+$ , etc. (The aqueous species  $\text{CO}_2$  and  $\text{H}_2\text{CO}_3$  are two different chemical entities.<sup>1,10</sup>) Hydrolyzed  $\text{M}^{\text{IV}}$  in acid solution has usually been represented in Table 1 as  $\text{M(OH)}_2^{2+}$ , although in many cases this is an oversimplification.<sup>8</sup> For acids, ionizable hydrogens precede the central atom while nonionizable hydrogens follow it; thus phosphoric acid has been written as  $\text{H}_3\text{PO}_4$ , phosphorous acid as  $\text{H}_2\text{PHO}_3$ , and hypophosphorous acid as  $\text{HPH}_2\text{O}_2$ . Boric acid, which accepts  $\text{OH}^-$  rather than donates  $\text{H}^+$ , has been written as  $\text{B(OH)}_3$  rather than as  $\text{H}_3\text{BO}_3$  or as (structurally incorrect)  $\text{HBO}_2$ . Rhenium hydride species<sup>10</sup> (which include  $\text{ReH}_9^{2-}$ ) are represented in Table 1 as  $\text{ReH}$  rather than as  $\text{Re}^-$ ; as a result, the  $E^{\circ}$  value for the  $\text{Re}/\text{Re}^{-1}$  half-reaction is calculated to decrease with increasing  $p\text{H}$ , avoiding the unlikely prediction<sup>6,7</sup> that metallic rhenium disproportionates above  $p\text{H} 6$ .

**4. Standard Electrode Potentials of Half-Reactions and Complete Cell Reactions**

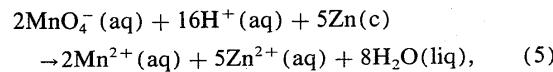
In accord with the IUPAC-Gibbs-Stockholm convention,<sup>2</sup>  $E^{\circ}$  for a half-reaction is considered positive in this report if the oxidized form at unit activity is a better oxidizing agent than  $\text{H}^+$  (aq,  $a = 1$  m), and negative if the reduced form at unit activity is a better reducing agent than  $\text{H}_2$  (g,  $f = 1$  atm). For example, for the half-reaction



$\text{MnO}_4^-$  (aq,  $a = 1$  m) is a better oxidizing agent than  $\text{H}^+$  (aq,  $a = 1$  m), and  $E^{\circ}(\text{MnO}_4^-, \text{H}^+/\text{Mn}^{2+}) = 1.507$  V. For the half-reaction



$\text{Zn(c)}$  is a better reducing agent than  $\text{H}_2$  (g,  $f = 1$  atm), and  $E^{\circ}(\text{Zn}^{2+}/\text{Zn(c)}) = - 0.762$  V. For the complete cell reaction



$E^{\circ}_{\text{cell}}[\text{Zn(c)}/\text{Zn}^{2+} // \text{MnO}_4^-]$ ,  $\text{H}^+/\text{Mn}^{2+}] = 1.507 - (- 0.762) = 2.269$  V. The positive sign of  $E^{\circ}_{\text{cell}}$  indicates

that the reaction described by Eq. (5) is spontaneous under standard conditions at 298.15 K.

For the half-reactions described by Eqs. (3) and (4),  $(dE^0/dT)_{298} = -0.646$  and  $0.119 \text{ mV/K}$ , respectively. Therefore, for the reaction described by Eq. (5),  $(dE^0/dT)_{298} = -0.646 - (0.119) = -0.765 \text{ mV/K} = -0.000765 \text{ V/K}$ . From Eq. (2) (using  $E_{298}^0 = 2.269 \text{ V}$ ),

$$\begin{aligned} E_{373}^0 &= 2.269 + (373.15 - 298.15)(-0.000765) \\ &= 2.212 \text{ V}. \end{aligned} \quad (6)$$

This result is slightly in error because the variation of  $E^0$  with temperature is only approximately linear. Deviations from linearity are discussed in Sec. 8.

## 5. Thermodynamic Changes Associated with Half-Reactions and Complete Cell Reactions

The standard Gibbs energy change associated with a half-reaction or a complete cell reaction at 298.15 K may be calculated by

$$\Delta G_{298}^0 = -nFE_{298}^0, \quad (7)$$

where  $n$  is the number of electrochemical equivalents in the half-reaction or complete cell reaction and  $F$  is the Faraday constant [ $9.648\ 530\ 9 \times 10^4 \text{ J/(V}\cdot\text{mol)}$ ].<sup>14</sup> By combining Eqs. (2) and (7), one may calculate approximately the standard Gibbs energy change associated with a half-reaction or a complete cell reaction at any temperature  $T$ :

$$\begin{aligned} \Delta G_T^0 &= -nFE_T^0 \\ &= -nF [E_{298}^0 + (T - 298.15) \cdot (dE^0/dT)_{298}]. \end{aligned} \quad (8)$$

Using the reaction described by Eq. (5) as an example (with  $n = 10$ ),

$$\begin{aligned} \Delta G_{298}^0 &= -(10)(9.648\ 530\ 9 \times 10^4)(2.269) \\ &= -2.189 \times 10^6 \text{ J} = -2189 \text{ kJ}. \end{aligned} \quad (9)$$

$$\begin{aligned} \Delta G_{373}^0 &= -(10)(9.648\ 530\ 9 \times 10^4)[2.269 \\ &\quad + (373.15 - 298.15)(-0.000765)] \\ &= -2.134 \times 10^6 \text{ J} = -2134 \text{ kJ}. \end{aligned} \quad (10)$$

The changes in the standard entropy and enthalpy associated with a half-reaction or a complete cell reaction at 298.15 K may be calculated by

$$\Delta S_{298}^0 = -d(\Delta G_{298}^0)/dT = nF(dE^0/dT)_{298}, \quad (11)$$

$$\begin{aligned} \Delta H_{298}^0 &= \Delta G_{298}^0 + 298.15 \cdot \Delta S_{298}^0 \\ &= nF [-E_{298}^0 + 298.15(dE^0/dT)_{298}]. \end{aligned} \quad (12)$$

Using the reaction described by Eq. (5) as an example,

$$\begin{aligned} \Delta S_{298}^0 &= (10)(9.648\ 530\ 9 \times 10^4)(-0.000765) \\ &= -738 \text{ J/K}, \end{aligned} \quad (13)$$

$$\begin{aligned} \Delta H_{298}^0 &= (10)(9.648\ 530\ 9 \times 10^4)[-2.269 \\ &\quad + 298.15(-0.000765)] \\ &= -2.409 \times 10^6 \text{ J} = -2409 \text{ kJ}. \end{aligned} \quad (14)$$

## 6. Thermodynamic Properties of Individual Chemical Species

By convention, the thermodynamics of formation ( $\Delta_f G^0$ ,  $\Delta_f S^0$ , and  $\Delta_f H^0$ ) of free elements in their standard states, of  $\text{H}^+$  (aq), and of  $e^-$  (electrochemical equivalent), are equal to zero at all temperatures. For the half-reaction

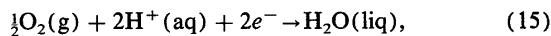


Table 1 gives  $E_{298}^0 = 1.2291 \text{ V}$  and  $(dE^0/dT)_{298} = -0.8456 \text{ mV/K}$ . Thus, from Eqs. (7), (11), and (12), Eq. (15) gives  $\Delta_f G^0(\text{H}_2\text{O}, \text{liq}) = -237.18 \text{ kJ/mol}$ ,  $\Delta_f S^0(\text{H}_2\text{O}, \text{liq}) = -163.18 \text{ J/(K}\cdot\text{mol)}$  and  $\Delta_f H^0(\text{H}_2\text{O}, \text{liq}) = -285.83 \text{ kJ/mol}$  at 298.15 K. For the half-reactions

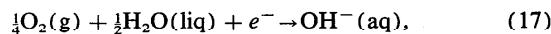
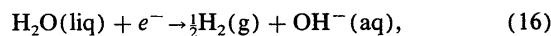


Table 1 gives  $E_{298}^0 = -0.8280 \text{ V}$  and  $(dE^0/dT)_{298} = -0.8360 \text{ mV/K}$  for Eq. (16), and  $E_{298}^0 = 0.4011 \text{ V}$  and  $(dE^0/dT)_{298} = -1.6816 \text{ mV/K}$  for Eq. (17). Thus, from Eqs. (7), (11), and (12), either Eq. (16) or (17) gives  $\Delta_f G^0(\text{OH}^-, \text{aq}) = -157.29 \text{ kJ/mol}$ ,  $\Delta_f S^0(\text{OH}^-, \text{aq}) = -243.84 \text{ J/(K mol)}$  and  $\Delta_f H^0(\text{OH}^-, \text{aq}) = -229.99 \text{ kJ/mol}$  at 298.15 K.

The thermodynamics of formation of  $\text{H}_2\text{O}(\text{liq})$  and  $\text{OH}^-(\text{aq})$  at 298.15 K may be used to retrieve standard Gibbs energies, entropies and enthalpies of formation of other chemical species at 298.15 K, by applying Eqs. (7), (11), and (12) to other half-reactions relating the species of interest to the free elements in their standard states. For example, for the half-reaction

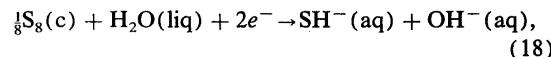
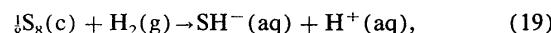


Table 1 gives  $E_{298}^0 = -0.476 \text{ V}$  and  $(dE^0/dT)_{298} = -0.934 \text{ mV/K}$ . From Eqs. (7), (11), and (12),  $\Delta G_{298}^0$ ,  $\Delta S_{298}^0$  and  $\Delta H_{298}^0$  for this half-reaction are  $91.9 \text{ kJ/mol}$ ,  $-180.3 \text{ J/(K mol)}$  and  $38.1 \text{ kJ/mol}$ , respectively. From the thermodynamics of formation of  $\text{H}_2\text{O}(\text{liq})$  and  $\text{OH}^-(\text{aq})$  given above,  $\Delta_f G^0(\text{SH}^-, \text{aq}) = 12.0 \text{ kJ/mol}$ ,  $\Delta_f S^0(\text{SH}^-, \text{aq}) = -99.6 \text{ J/(K mol)}$  and  $\Delta_f H^0(\text{SH}^-, \text{aq}) = -17.7 \text{ kJ/mol}$  at 298.15 K.

"Third-law" standard entropies of chemical species at 298.15 K may be calculated by combining standard entropies of formation derived through Eq. (11) with third-law standard entropies of the free elements in their standard states at 298.15 K. The latter are provided in Table 2, arranged by Periodic Table family for easy access. For example, for the reaction



$\Delta S^0 = \Delta_f S^0(\text{SH}^-, \text{aq}) = -99.6 \text{ J/(K mol)}$ ; combination with  $S^0(\frac{1}{8}\text{S}_8, \text{c}) = 31.8 \text{ J/(K mol)}$  and  $S^0(\text{H}_2, \text{g}) = 130.574 \text{ J/(K mol)}$  from Table 2 gives  $S^0(\text{SH}^-, \text{aq}) = 62.8 \text{ J/(K mol)}$ .

## 7. Calculations for Nonstandard Conditions

The potential associated with a half-reaction or a complete cell reaction under nonstandard conditions may be calculated by the Nernst equation

Table 2. Third-Law Standard Entropies at 298.15 K<sup>a</sup>

Element	S° (J/(K·mol))	Element	S° (J/(K·mol))	Element	S° (J/(K·mol))
H <sub>2</sub> (g)	130.574	Pu (c, α)	56.1 <sup>b</sup>	Zn (c)	41.63
Li (c)	29.12	Am (c, α)	54.5 <sup>b</sup>	Cd (c, γ)	51.76
Na (c)	51.21	Cm (c, α)	72.0 <sup>b</sup>	Hg (liq)	76.02
K (c)	64.18	Bk (c, α)	78.2 <sup>b</sup>	B <sub>12</sub> (c, β)	70.3
Rb (c)	76.78	Cf (c)	(80.) <sup>c</sup>	Al (c)	28.33
Cs (c)	85.23	Es (c)	(90.) <sup>c</sup>	Ga (c)	40.88
Fr (c)	95.4	Fm (c)	(88.) <sup>c</sup>	In (c)	57.82
Be (c)	9.50	Md (c)	(84.) <sup>c</sup>	Tl (c)	64.18
Mg (c)	32.68	No (c)	(66.) <sup>c</sup>	C (c, graphite)	5.740
Ca (c, α)	41.42	Lr (c)	(56.) <sup>c</sup>	Si (c)	18.83
Sr (c, α)	52.3	Ti (c, α)	30.63	Ge (c)	31.09
Ba (c)	62.8	Zr (c)	38.99	Sn (c, l-white)	51.55
Ra (c)	71.	Hf (c)	43.56	Pb (c)	64.81
Sc (c)	34.64	V (c)	28.91	N <sub>2</sub> (g)	191.50
Y (c)	44.43	Nb (c)	36.40	P (c, red)	22.80
La (c, α)	57.0 <sup>b</sup>	Ta (c)	41.51	P <sub>4</sub> (c, white)	164.3
Ce (c, γ)	72.0	Cr (c)	23.77	As (c, α-gray)	35.1
Pr (c, α)	73.2	Mo (c)	28.66	Sb (c, III-gray)	45.60
Nd (c)	71.5	W (c)	32.64	Bi (c)	56.74
Pm (c)	71. <sup>b</sup>	Mn (c, α)	32.01	O <sub>2</sub> (g)	205.029
Sm (c)	69.58	Tc (c)	(33.) <sup>d</sup>	S <sub>8</sub> (c, rhombic)	254.4
Eu (c)	77.78	Re (c)	36.86	Se (c, gray)	42.442
Gd (c)	68.07	Fe (c, α)	27.28	Te (c, α)	49.71
Tb (c)	73.22	Ru (c)	28.53	Po (c, α)	(60.) <sup>d</sup>
Dy (c)	74.77	Os (c)	32.6	F <sub>2</sub> (g)	202.67
Ho (c)	75.3	Co (c, α)	30.04	Cl <sub>2</sub> (g)	222.957
Er (c)	73.18	Rh (c)	31.51	Br <sub>2</sub> (liq)	152.231
Tm (c)	74.01	Ir (c)	35.48	I <sub>2</sub> (c)	116.135
Yb (c)	59.87	Ni (c)	29.87	At (c)	(65.) <sup>d</sup>
Lu (c)	50.96	Pd (c)	37.57	He (g)	126.041
Ac (c, α)	62.8 <sup>b</sup>	Pt (c)	41.63	Ne (g)	146.219
Tb (c, α)	53.39	Cu (c)	33.150	Ar (g)	154.734
Pa (c, α)	51.9	Ag (c)	42.55	Kr (g)	163.973
U (c, α)	50.21	Au (c)	47.40	Xe (g)	169.54
Np (c, α)	50.46 <sup>b</sup>			Rn (g)	176.1

## Notes to Table 2.

<sup>a</sup>References 6 and 7, except as noted.<sup>b</sup>Reference 9.<sup>c</sup>Reference 13.<sup>d</sup>This work.

$$E_T = E_{298}^0 - \frac{RT}{nF} \cdot \ln Q_T$$

$$= E_{298}^0 - \frac{(\ln 10) \cdot RT}{nF} \cdot \log Q_T, \quad (20)$$

where  $E_T^0$  is the standard electrode potential at the temperature under consideration,  $R$  is the gas constant [8.314 510 J/

(K mol)],<sup>14</sup>  $T$  is the temperature in Kelvin,  $n$  is the number of electrochemical equivalents in the half-reaction or complete cell reaction, and  $F$  is the Faraday constant.  $Q_T$  is the activity quotient at the temperature  $T$ , which has the same form as the equilibrium constant  $K_T$  for the reaction under consideration, but uses the actual activities rather than the activities at equilibrium.  $\ln 10$  is the conversion factor between natural and common logarithms (2.302 585 093). Substituting the numerical values for the physical constants into Eq. (20)<sup>14</sup> gives, at 298.15 K,

$$E_{298} = E_{298}^0 - (0.059 159 7/n) \cdot \log Q_{298}. \quad (21)$$

Using the reaction described by Eq. (5) as an example,

$$E_{298} = 2.269 - \frac{0.059 159 7}{10} \cdot \log \frac{(a_{\text{Mn}2+})^2 (a_{\text{Zn}2+})^5}{(a_{\text{Mn}04-})^2 (a_{\text{H}+})^{16}}. \quad (22)$$

Zinc and water do not appear in Eq. (22) because the activities of pure solids and liquids are taken as unity.

At equilibrium,  $E_T = 0$  and  $Q_T = K_T$ . Making these substitutions into Eqs. (20) and (21) gives, upon rearrangement,

$$\log K_T = [nFE_T^0 / (\ln 10) \cdot RT] \quad (23)$$

$$\log K_{298} = (nE_{298}^0 / 0.059 159 7). \quad (24)$$

For the reaction described by Eq. (5) (using  $n = 10$  and  $E_{298}^0 = 2.269$  V),  $\log K_{298} = 383.5$  and  $K_{298} = 3 \times 10^{383}$ .

Combinations of Eqs. (2) and (23) gives

$$\log K_T = \left\{ nF \left[ E_{298}^0 + (T - 298.15) \cdot \left( \frac{dE^0}{dT} \right)_{298} \right] \right. \\ \left. + (\ln 10) \cdot RT \right\}. \quad (25)$$

Substituting the numerical values for the physical constants into Eq. (25)<sup>14</sup> gives

$$\log K_T = \left\{ 5039.75n \left[ E_{298}^0 \right. \right. \\ \left. \left. + (T - 298.15) \cdot \left( \frac{dE^0}{dT} \right)_{298} \right] \right\} / T. \quad (26)$$

For the reaction described by Eq. (5) [using  $n = 10$ ,  $E_{298}^0 = 2.269$  V and  $(dE^0/dT)_{298} = -0.765$  mV/K],  $\log K_{373} = 298.7$  and  $K_{373} = 5 \times 10^{298}$ .

## 8. Second Temperature Coefficients

All equations and examples given to this point for temperatures other than 298.15 K have assumed that Eq. (2) is perfectly accurate, i.e., that  $E^0$  is a linear function of temperature. This would be the case if the standard isobaric heat capacity change,  $\Delta C_p^0$ , were equal to zero. In reality it is not, but the effect of  $\Delta C_p^0$  on  $\Delta G^0$  and  $E^0$  is less than that on  $\Delta H^0$  and  $\Delta S^0$  because  $d\Delta H^0/dT$  and  $d\Delta S^0/dT$  have the same algebraic sign. Salvi and de Bethune<sup>3</sup> have expanded Eq. (2) as

$$E_T^0 = E_{298}^0 + (T - 298.15) \cdot \left( \frac{dE^0}{dT} \right)_{298} \\ + 0.5(T - 298.15)^2 \cdot \left( \frac{d^2E^0}{dT^2} \right)_{298}, \quad (27)$$

where  $(d^2E^0/dT^2)_{298}$  is the second temperature coefficient of the standard electrode potential. According to Salvi and de Bethune  $(d^2E^0/dT^2)_{298}$  may be calculated from  $\Delta C_p^0$  by the expression

$$\left(\frac{d^2E^0}{dT^2}\right)_{298} = \Delta C_p^0 / (298.15nF). \quad (28)$$

Second temperature coefficients may be conveniently expressed in microvolts per Kelvin squared,  $\mu\text{V}/\text{K}^2$ .

For the reaction described by Eq. (5)  $(d^2E^0/dT^2)_{298}$  may be evaluated from heat capacity data<sup>6,7</sup> as  $3.4 \mu\text{V}/\text{K}^2$ . In accord with Eq. (27), this changes  $E_{373}^0$  from 2.212 V [Eq. (6)] to 2.222 V. For many half-reactions and complete cell reactions, the typical effect of the second temperature coefficient on  $E^0$  in going from 298.15 to 373.15 K is only  $\sim 5\text{--}10$  mV, which is often less than 10% of the effect of  $dE^0/dT$  on  $E^0$  over the same temperature range, and smaller than the uncertainties associated with many  $E^0$  values at 298.15 K.

Second temperature coefficients of standard electrode potentials involving ions in water are given in Table 3, as calculated from the heat capacities selected by NBS.<sup>6,7</sup> It appears that heat capacity changes involving aquo-ions have generally not been well determined. The values which can be derived from Refs. 3 and 8(b) show poor agreement with those selected by NBS,<sup>6,7</sup> differing occasionally even in algebraic sign. On the other hand, the heat capacities of many crystalline oxides and hydroxides are accurately known,<sup>6,7</sup> but display such regularity that it is more efficient to summarize  $d^2E^0/dT^2$  values for half-reactions involving these substances in terms of equations (*vide infra*) than it is to tabulate the individual values.

Table 3. Second Temperature Coefficients at 298.15 K<sup>a,b</sup>

Half-Reaction	$d^2E^0/dT^2$ ( $\mu\text{V}/\text{K}^2$ )	Half-Reaction	$d^2E^0/dT^2$ ( $\mu\text{V}/\text{K}^2$ )
$\text{H}^+ / \text{H}_2(\text{g})$	0.0000	$\text{Yb}^{3+} / \text{Yb}(\text{c})$	-0.5
$\text{H}_2\text{O}(\text{liq}) / \text{H}_2(\text{g}), \text{OH}^-$	-7.78	$\text{Lu}^{3+} / \text{Lu}(\text{c})$	-0.5
$\text{Li}^+ / \text{Li}(\text{c})$	-2.02	$\text{MnO}_4^- \cdot \text{H}^+ / \text{Mn}^{2+}$	2.5
$\text{Na}^+ / \text{Na}(\text{c})$	-1.13	$\text{Mn}^{2+} / \text{Mn}(\text{c})$	-0.9
$\text{K}^+ / \text{K}(\text{c})$	-0.23	$\text{ReO}_4^- \cdot \text{H}^+ / \text{Re}(\text{c})$	1.19
$\text{Cs}^+ / \text{Cs}(\text{c})$	0.98	$\text{Ag}^+ / \text{Ag}(\text{c})$	-0.38
$\text{La}^{3+} / \text{La}(\text{c})$	0.0	$\text{Zn}^{2+} / \text{Zn}(\text{c})$	-0.9
$\text{Pr}^{3+} / \text{Pr}(\text{c})$	0.2	$\text{NO}_3^- \cdot \text{H}^+ / \text{N}_2(\text{g})$	1.77
$\text{Nd}^{3+} / \text{Nd}(\text{c})$	0.1	$\text{N}_2(\text{g}), \text{H}^+ / \text{NH}_4^+$	0.26
$\text{Sm}^{3+} / \text{Sm}(\text{c})$	0.1	$\text{O}_2(\text{g}), \text{H}^+ / \text{H}_2\text{O}(\text{liq})$	0.5525
$\text{Eu}^{3+} / \text{Eu}(\text{c})$	-0.3	$\text{O}_2(\text{g}) / \text{OH}^-$	7.23
$\text{Gd}^{3+} / \text{Gd}(\text{c})$	-0.2	$\text{SO}_4^{2-}, \text{H}^+ / \text{S}_8(\text{c})$	3.1
$\text{Tb}^{3+} / \text{Tb}(\text{c})$	-0.4	$\text{F}_2(\text{g}) / \text{F}^-$	-4.75
$\text{Dy}^{3+} / \text{Dy}(\text{c})$	-0.4	$\text{Cl}_2(\text{g}) / \text{Cl}^-$	-5.83
$\text{Ho}^{3+} / \text{Ho}(\text{c})$	-0.4	$\text{Br}_2(\text{g}) / \text{Br}^-$	-6.06
$\text{Er}^{3+} / \text{Er}(\text{c})$	-0.4	$\text{Br}_2(\text{liq}) / \text{Br}^-$	-6.75
$\text{Tm}^{3+} / \text{Tm}(\text{c})$	-0.5	$\text{I}_2(\text{c}) / \text{I}^-$	-6.39

Notes to Table 3:

<sup>a</sup>References 6 and 7

<sup>b</sup>See also Eqs. (31), (34) and (36).

## 9. Estimated Values

The tabulation of estimated thermodynamic quantities fulfills three very important functions. First, for a known chemical species, an estimated value offers a temporary semiquantitative means of predicting chemical reactivity, e.g., an  $E^0$  value in an activity series. Second, the tabulation of estimated thermodynamic quantities for a known species emphasizes the gaps in our knowledge (provided that one clearly labels such values as estimates), and can serve as the incentive for new research. (It is worth noting here that  $\sim 30\%$  of the frequently quoted  $dE^0/dT$  values listed by de Bethune *et al.*<sup>2-4</sup> have been derived from *estimated* standard entropies given by Latimer,<sup>1</sup> but have not been identified as estimates.) Third, for an unknown species, an estimated standard Gibbs energy of formation based on a reasonable method of prediction can provide insight as to why the species might be unknown. In this report, estimated values have been enclosed in parentheses to clearly distinguish them from experimentally based data. The author accepts full responsibility for all estimated values in this report.

There are occasions where  $\Delta H^0$  for a half-reaction is experimentally known but both  $\Delta G^0$  and  $\Delta S^0$  are estimated. As a result, both  $E^0$  and  $dE^0/dT$  for the half-reaction are estimated quantities and are listed in Table 1 with parentheses. However, it is noted in Table 1 that  $E^0$  and  $dE^0/dT$  for the half-reaction correspond to an experimental  $\Delta H^0$ .

The following list of general methods for the estimation of thermodynamic quantities, while not exhaustive, is indicative of the logic involved.

One general method of thermodynamic prediction involves the fitting of ion hydration and lattice thermodynamics of chemically similar species to simple ionic charge-size functions. Examples of this method may be found in Refs. 11-13.

Latimer<sup>1</sup> has provided equations for the estimation of standard entropies of solids and aqueous molecules and ions. The reliability of Latimer's equations can be increased by restricting comparisons to chemically similar species and correcting for differences in atomic or ionic size and mass (e.g., the estimation of the standard entropy of  $\text{FeO}_4^{2-}$  by comparison with  $\text{CrO}_4^{2-}$  and  $\text{MnO}_4^{2-}$ ). Theoretical corrections can also be made for magnetic effects due to the presence of unpaired electrons.<sup>11-13</sup>

Baes and Mesmer<sup>8</sup> have shown that useful empirical relationships exist among the thermodynamics of hydrolytic processes, such as in the solubility products of oxides and hydroxides and their acid-base behavior in terms of aquo-species such as  $\text{M}^{z+}$  and  $\text{MO}_a(\text{OH})^{(z-2a-b)+}$ . Useful relationships also exist among these processes and such parameters as ionic charge, radius and electron configuration, and location in the Periodic Table.<sup>8</sup> The latter can also be used as a guide in predicting trends in  $E^0$  values (e.g., for Po, At, and Rn species by extrapolation from their lighter congeners).

Latimer<sup>1</sup> has illustrated a procedure by which one may assign upper and lower limits to a standard electrode potential on the basis of observed (or expected) chemical behavior. This method by itself is not always sufficient to assign a

specific numerical value to a half-reaction, but it serves as a useful guide when combined with other methods. In the present work, the necessary descriptive chemistry for this procedure has been taken from Latimer,<sup>1</sup> Baes and Messmer,<sup>8(a)</sup> Bard *et al.*<sup>9</sup> and especially Cotton and Wilkinson.<sup>10</sup>

The following specific examples of estimated values are worthy of mention.

H<sup>-</sup>: Estimated by assuming that the thermodynamics of dissolution of the alkali hydrides lie between those of the alkali fluorides and chlorides,<sup>6,7</sup> and may be interpolated on the basis of the relative internuclear distances in MF, MH, and MCl. Other assumptions lead to similar results.<sup>1,9</sup>

Fr and Ra species: Estimated from thermochemical cycles extrapolated from the lighter alkali and alkaline earth metals, by the methods described in Refs. 11-13.

Pr<sup>2+</sup>, Nd<sup>2+</sup>, Pm species, Dy<sup>2+</sup>-Tm<sup>2+</sup>, Pu<sup>2+</sup>, Am<sup>2+</sup>, Bk<sup>2+</sup>, and Es-Lr species: Estimated from thermochemical cycles by the methods described in Refs. 11-13.

Ti<sup>2+</sup>, Nb<sup>3+</sup>, Ta<sup>3+</sup>, Mo<sup>3+</sup>, Re<sup>3+</sup>, Ru<sup>3+</sup>, Os<sup>3+</sup>, Ir<sup>3+</sup>, Ni<sup>3+</sup>, Ag<sup>3+</sup>, Au<sup>3+</sup>, and Ge<sup>2+</sup>: Estimated by assuming a periodic variation in the thermodynamics of dissolution of oxides, hydroxides and halides, fitting to known cases<sup>6,7</sup> for neighboring elements in the Periodic Table (e.g., Ti<sup>2+</sup> by interpolation between Ca<sup>2+</sup> and V<sup>2+</sup>, Cr<sup>2+</sup>).

Sc<sup>2+</sup>, W<sup>3+</sup>, Tc<sup>2+</sup>, Tc<sup>3+</sup>, Cu<sup>3+</sup>, and Au<sup>2+</sup>: Estimated by assuming a periodic variation in the thermodynamics of ion hydration, fitting to known or estimated cases for neighboring elements in the Periodic Table (e.g., Sc<sup>2+</sup> by interpolation between Ca<sup>2+</sup> and Ti<sup>2+</sup>, V<sup>2+</sup>).

AlH<sub>4</sub><sup>-</sup>: Estimated by assuming that the thermodynamics of dissolution of MAIH<sub>4</sub> (M = Li, Na, K) are similar to those of MBH<sub>4</sub>.<sup>6,7</sup>

OH: Estimated by assuming that the thermodynamics of dissolution of OH(g) are the same as those of HF(g).<sup>6,7</sup> Other assumptions lead to similar results.<sup>1,9</sup>

O<sub>3</sub><sup>-</sup>: Estimated by noting that  $\Delta G^0$  for the reaction O<sub>2</sub>(g) + O<sup>-</sup> → O<sub>3</sub><sup>-</sup> is near zero.<sup>9</sup>

A number of estimated half-reactions in Table 1 involve doubtful chemical species of three main types:

(1) Species which are known in certain nonaqueous environments but which have only a transient existence in water. Examples include Tm<sup>2+</sup>, AlH<sub>4</sub><sup>-</sup>, and SiO(c).

(2) Species which have been claimed to exist or form in aqueous media but which have been improperly characterized and require further investigation. Examples include RhO<sub>4</sub><sup>2-</sup>, NiO<sub>2</sub>(c), and XeO.

(3) Species which are essentially nonexistent in chemical environments but which have been included in Table 1 to illustrate probable periodic trends. Examples include Sc<sup>2+</sup>, UO<sub>2</sub>OH(c), and Au<sup>2+</sup>.

It is worth noting that the distinction among the three different types of doubtful chemical species is not always clear-cut. Half-reactions involving doubtful species have been noted as such in Table 1.

Iron may be used as an example of the details involved in the thermodynamic calculations for an element. All thermodynamic data for Fe(c,α), Fe<sub>0.947</sub>O(c), Fe(OH)<sub>2</sub>(c), Fe<sub>3</sub>O<sub>4</sub>(c), Fe<sub>2</sub>O<sub>3</sub>(c,α) and Fe(OH)<sub>3</sub>(pt),  $\Delta_f H^0$  for Fe<sup>2+</sup>, FeOOH(c), Fe<sup>3+</sup>, FeOH<sup>2+</sup>, and Fe<sub>2</sub>(OH)<sub>2</sub><sup>+</sup>, and  $\Delta_f G^0$

for Fe(OH)<sub>2</sub><sup>-</sup> have been taken from Refs. 6 and 7.  $\Delta_f G^0$  for Fe<sup>2+</sup> and Fe<sup>3+</sup> have been taken from the recommended  $E^0$  values in Ref. 9 (which also discusses the problems associated with the reproducibility of iron electrodes). All thermodynamic data for FeOH<sup>+</sup>, FeOH<sup>2+</sup>, and Fe<sub>2</sub>(OH)<sub>2</sub><sup>+</sup>, and  $\Delta_f G^0$  for Fe(OH)<sub>2</sub>(pt), Fe(OH)<sub>4</sub><sup>2-</sup>, and Fe(OH)<sub>4</sub><sup>-</sup> have been deduced from the equilibrium data given in Ref. 8.  $\Delta_f H^0$  for FeO<sub>4</sub><sup>2-</sup> has been taken from Ref. 2. The following quantities have been estimated in this work:  $S^0$  for Fe(OH)<sub>2</sub>(pt), FeOOH(c), Fe(OH)<sub>4</sub><sup>-</sup>, and FeO<sub>4</sub><sup>2-</sup> (the latter three by comparison with AlOOH(c), Al(OH)<sub>4</sub><sup>-</sup> and CrO<sub>4</sub><sup>2-</sup> and MnO<sub>4</sub><sup>2-</sup>), and  $\Delta_f G^0$  for HFeO<sub>4</sub><sup>-</sup> (by comparison with the acid dissociation constant for HCrO<sub>4</sub><sup>-</sup>).

For half-reactions of the type: M<sup>+</sup>/M (free metal), the experimental  $E^0$ ,  $dE^0/dT$  and  $d^2E^0/dT^2$  values show interesting correlations with electronegativity ( $X$ ),<sup>15</sup> ionic charge ( $z$ ) and ionic radius ( $r$ , nm)<sup>15</sup>:

$$E_{298}^0 + 4.5 = 3.4 \cdot X - \frac{0.4}{r + 0.138} \pm 0.4 \text{ V}, \quad (29)$$

$$\left( \frac{dE^0}{dT} \right)_{298} + 0.906 = \frac{0.484}{r + 0.138} - \frac{2.90}{1.5^z} \pm 0.09 \text{ mV/K}, \quad (30)$$

$$\left( \frac{d^2E^0}{dT^2} \right)_{298} = 27r - \frac{2.0}{1.5^z} - 2.4 \pm 0.2 \text{ } \mu\text{V/K}^2. \quad (31)$$

The absolute potential and temperature coefficient of the SHE are  $4.5 \pm 0.1$  V and  $0.906 \pm 0.015$  mV/K, respectively,<sup>9,12</sup> while the radius of a water molecule is 0.138 nm.<sup>15</sup> The other parameters in Eqs. (29)-(31) have no physical significance.

For half-reactions of the type: Oxide (c), H<sup>+</sup>/M (free metal), the corresponding equations are

$$E_{298}^0 = 2.3X - \frac{0.8}{r + 0.140} - 0.6 \pm 0.4 \text{ V}, \quad (32)$$

$$\left( \frac{dE^0}{dT} \right)_{298} = -0.37 \pm 0.04 \text{ mV/K}, \quad (33)$$

$$\left( \frac{d^2E^0}{dT^2} \right)_{298} = -0.52 \pm 0.08 \text{ } \mu\text{V/K}^2. \quad (34)$$

The radius of oxide ion is 0.140 nm.<sup>15</sup> The other parameters in Eqs. (32)-(34) have no physical significance.

For half-reactions of the type: Hydroxide (c), H<sup>+</sup>/M (free metal), the equation for  $E_{298}^0$  is essentially the same as for oxides, i.e., Eq. (32). The equations for  $(dE^0/dT)_{298}$  and  $(d^2E^0/dT^2)_{298}$  are the following:

$$\left( \frac{dE^0}{dT} \right)_{298} = -0.17 \pm 0.05 \text{ mV/K}; \quad (35)$$

$$\left( \frac{d^2E^0}{dT^2} \right)_{298} = 1.29 \pm 0.09 \text{ } \mu\text{V/K}^2. \quad (36)$$

The parameters in Eqs. (35) and (36) have no physical significance. At pH = 13.996, the  $E^0$  values for Eq. (32) are 0.8280 V more negative, the  $dE^0/dT$  values for Eqs. (33) and (35) are 0.8360 mV/K more negative, and the  $d^2E^0/dT^2$  values for Eqs. (34) and (36) are 7.78  $\mu\text{V/K}^2$  more negative.

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