

UNIVERSITY OF ESWATINI
DEPARTMENT OF CHEMISTRY



SUPPLEMENTARY EXAMINATION 2020/2021

TITLE OF PAPER: ANALYTICAL CHEMISTRY II
COURSE NUMBER: CHE 411
TIME ALLOWED: THREE (3) HOURS
INSTRUCTIONS: ANSWER ANY FOUR (4) QUESTIONS

Special Requirements

1. Data sheet.
2. Graph Paper

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

QUESTION 1 [25]

- a) In Polarography, what is meant by:
- i) The over potential [2]
 - ii) The charging current (use a diagram to illustrate) [3]
- b) Describe migration as one of the main mass transfer processes in polarography, state whether the process is desired, and what means are put in place to eliminate it if undesired. [3]
- c) Use Fick's Law and the Cottrell equation to derive the Ilkovic equation for quantitative polarography. [5]
- d) With the aid of a large, labeled diagram, explain how the dropping mercury electrode (DME) works. [4]
- e) Discuss three (3) properties of mercury that makes it suitable for polarographic work. [3]
- f) The standard addition method in Polarography is most useful when the sample matrix is complex. A 50ml waste water sample from a Nickel mine dump gave a wave height of $5.38\mu\text{A}$ in a polarographic analysis. When 0.500 ml of solution containing 25 mM Ni^{2+} was added, the wave height measured $8.25\mu\text{A}$. Calculate the concentration of nickel in the unknown (in ppm), given that supporting electrolyte alone gave a residual current of $0.05\mu\text{A}$. [5]

QUESTION 2 [25]

- a) Apart from migration, how else do electroactive ions in solution move towards the mercury electrode in polarography? [2]
- b) In polarography, the current is sometimes observed to "overshoot" the diffusion current before settling back down at the plateau. What causes these current maxima, and how are they eliminated? [2]
- c) In polarography, analyses are conducted within an electrochemical window governed by the anodic and cathode limits. Discuss the origins of these limits with the aid of chemical equations. [4]
- d) Oxygen waves are a nuisance in the polarographic determinations of heavy metals. However, levels of dissolved oxygen in water samples can be measured polarographically.
- (i) Explain the origins of oxygen waves in polarography using supporting chemical equations. [4]
 - (ii) How is oxygen experimentally removed in polarography? [1]
 - (iii) Suppose tap water is scanned in a polarograph without deaeration, and the following is observed: $E_{1/2} = 0.05\text{ V}$; $i_{d, \text{ave}} = 1.81\mu\text{A}$, when the rate of flow of mercury is 2.00 mg/sec and the drop interval is 5 sec. Calculate the concentration of oxygen in the tap water in ppm units (diffusion coefficient $= 2.12 \times 10^{-5}\text{ cm}^2/\text{sec}$). [5]

- e) Sometimes useful information can be derived from the rising portion of the polarographic wave, for example, the number of electrons involved in the reduction. For benzoquinone, the following data were obtained in the rising portion of a polarographic wave:

<u>E vs SCE (V)</u>	<u>I μA</u>
+0.210	0.591
+0.190	0.146
+0.170	4.646
+0.150	6.299

Calculate the value of n if $I_{d,max} = 7.008 \mu\text{A}$.

[7]

QUESTION 3 [25]

- b) Describe the three (3) main requirements that enable an electrode to be considered a "reference electrode" [3]
- c) A reference electrode encountered frequently in analytical measurements is abbreviated "SCE".
- What does the acronym SCE stand for? [1]
 - Use a diagram to describe the components of the SCE. [3]
 - Write down the electrode reaction of the SCE and state its potential. [2]
 - State one disadvantage of the SCE [1]
- d) Unless it is to be measured, the liquid junction potential is undesirable in direct potentiometry. Explain the origin of a liquid junction potential in potentiometry, and indicate how it is eliminated. [3]
- e) With regards to the Orion fluoride ion selective electrode,
- Describe the structure of the electrode with the aid of a diagram. [4]
 - Calculate electromotive force of the electrode. [2]
 - Explain the role of each of three (3) components of TISAB used in conjunction with the fluoride electrode [6]

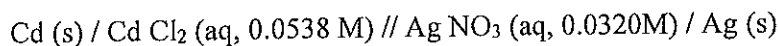
QUESTION 4 [25]

- a) Consider an amperometric titration of Pb^{2+} with titrant Titr^{2-} to form PbTitr using one polarized electrode.
- On one plot, sketch the current/voltage curves ($E_{1/2, \text{Pb}} = -0.4\text{V vs SCE}$) at the points at which the titration is 0%, 50%, 100%, 110% complete. [4]

- ii) If the dropping mercury electrode is held constant at -1.0V vs SCE, plot the resultant titration curve, assuming that the titrant is not electroreducible. [3]
- iii) Sketch the current/voltage curve that you would expect if Titr^{2-} , being non-electroreducible, were to be titrated with Pb^{2+} instead, at the points indicated in a (i) above. [4]
- iv) Sketch the shape of the titration curve that would result if Titr^{2-} were to be electroreducible as well. [3]
- b) Consider a biamperometric titration in which Fe^{2+} is titrated with Ce^{4+} according to the reaction:
 $\text{Fe}^{2+} + \text{Ce}^{4+} \longrightarrow \text{Fe}^{3+} + \text{Ce}^{3+}$. Given that the $\text{Fe}^{3+} / \text{Fe}^{2+}$ couple gets reduced at more negative potentials than the $\text{Ce}^{3+} / \text{Ce}^{4+}$ couple,
- i) Sketch the current-potential curves for points at which the fraction titrated is 0.1, 0.5, 1.0 and 1.2, assuming an impressed voltage of 100 mV across the electrodes [4]
- ii) Sketch the biamperometric titration curve for this system. [2]
- c) Explain how the pH glass electrode works using equations to support your answer. [5]

QUESTION 5 [25]

- (a) Write down the Nernst equation, and explain all the terms appearing in it. [3]
- (b) In potentiometry, potentials are measured relative to the standard hydrogen electrode (SHE) potential.
- i) Draw the SHE, and label all its components [4]
- ii) Write down the electrochemical equation taking place within the SHE and state its standard electrode potential [2]
- (c) For the electrochemical cell:



- i) What component is represented by the symbol “//”? [1]
- ii) How is it constructed? [2]
- iii) How does it work? [2]
- iv) Would the cell be galvanic as written? [4]
- (d) With regards to the pH glass membrane electrode, describe

- i) The terms k_{as} and β in the equation: $E = k_{as} - \beta (0.05916) \log \frac{A_{\text{H}^+, \text{inner}}}{A_{\text{H}^+, \text{outer}}}$

$A_{\text{H}^+, \text{outer}}$

- ii) The "alkaline error"
[1]
- iii) How the glass membrane can be modified to produce a sodium ion electrode [1]
- iv) The "acid error" [1]

QUESTION 6 [25]

- a) Modern methods in polarography seek to reduce capacitive current. Use a diagram to explain the origins of capacitive currents in polarography [3]
- b) Use diagrams to explain the difference in time behavior between capacitive current and Faradaic current, and their resulting superposition at the dropping mercury electrode. [3]
- c) Use diagrams to show the dependence of Faradaic and charging current on concentration. [3]
- d) Explain how the current is sampled in Tast Polarography, and compare the:
 - i) Resolution [1]
 - ii) Detection limits [1]
 - iii) Appearance of the polarogram [1]
 between Tast Polarography and Classical Polarography.
- e) Explain how the current is sampled in Differential Pulse Polarography (DPP), and compare the:
 - i) Resolution [1]
 - ii) Detection limits [1]
 - iii) Appearance of polarogram [1]
 between DPP and DC Polarography.
- f) Anodic Stripping Voltammetry (ASV) surpasses flame atomic absorption spectroscopy in the determination of ultra trace levels of lead in drinking water in terms of detection limits.
 - i) With the aid of a diagram, explain the instrumentation used in ASV. [4]
 - ii) Use a diagram and equations to describe the deposition step in ASV. [2]
 - iii) Use a diagram and equation to describe the stripping step in ASV. [2]
 - iv) Explain why it is more sensitive than FAAS in terms of detection limits. [2]

APPENDIX H Standard Reduction Potentials*

Reaction	E° (volts)	dE°/dT (mV/K)
Aluminum		
$\text{Al}^{3+} + 3e^- \rightleftharpoons \text{Al}(s)$	-1.677	0.533
$\text{AlCl}_4^{2+} + 3e^- \rightleftharpoons \text{Al}(s) + \text{Cl}^-$	-1.802	
$\text{AlF}_6^{3-} + 3e^- \rightleftharpoons \text{Al}(s) + 6\text{F}^-$	-2.069	
$\text{Al}(\text{OH})_4^- + 3e^- \rightleftharpoons \text{Al}(s) + 4\text{OH}^-$	-2.328	-1.13
Antimony		
$\text{SbO}^+ + 2\text{H}^+ + 3e^- \rightleftharpoons \text{Sb}(s) + \text{H}_2\text{O}$	0.208	
$\text{Sb}_2\text{O}_3(s) + 6\text{H}^+ + 6e^- \rightleftharpoons 2\text{Sb}(s) + 3\text{H}_2\text{O}$	0.147	-0.369
$\text{Sb}(s) + 3\text{H}^+ + 3e^- \rightleftharpoons \text{SbH}_3(g)$	-0.510	-0.030
Arsenic		
$\text{H}_3\text{AsO}_4 + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_3\text{AsO}_3 + \text{H}_2\text{O}$	0.575	-0.257
$\text{H}_3\text{AsO}_3 + 3\text{H}^+ + 3e^- \rightleftharpoons \text{As}(s) + 3\text{H}_2\text{O}$	0.247 5	-0.505
$\text{As}(s) + 3\text{H}^+ + 3e^- \rightleftharpoons \text{AsH}_3(g)$	-0.238	-0.029
Barium		
$\text{Ba}^{2+} + 2e^- + \text{Hg} \rightleftharpoons \text{Ba}(in\ Hg)$	-1.717	
$\text{Ba}^{2+} + 2e^- \rightleftharpoons \text{Ba}(s)$	-2.906	-0.401
Beryllium		
$\text{Be}^{2+} + 2e^- \rightleftharpoons \text{Be}(s)$	-1.968	0.60
Bismuth		
$\text{Bi}^{3+} + 3e^- \rightleftharpoons \text{Bi}(s)$	0.308	0.18
$\text{BiCl}_4^- + 3e^- \rightleftharpoons \text{Bi}(s) + 4\text{Cl}^-$	0.16	
$\text{BiOCl}(s) + 2\text{H}^+ + 3e^- \rightleftharpoons \text{Bi}(s) + \text{H}_2\text{O} + \text{Cl}^-$	0.160	
Boron		
$2\text{B}(s) + 6\text{H}^+ + 6e^- \rightleftharpoons \text{B}_2\text{H}_6(g)$	-0.150	-0.296
$\text{B}_4\text{O}_7^{2-} + 14\text{H}^+ + 12e^- \rightleftharpoons 4\text{B}(s) + 7\text{H}_2\text{O}$	-0.792	
$\text{B}(\text{OH})_3 + 3\text{H}^+ + 3e^- \rightleftharpoons \text{B}(s) + 3\text{H}_2\text{O}$	-0.889	-0.492
Bromine		
$\text{BrO}_4^- + 2\text{H}^+ + 2e^- \rightleftharpoons \text{BrO}_3^- + \text{H}_2\text{O}$	1.745	-0.511
$\text{HOBr} + \text{H}^+ + e^- \rightleftharpoons \frac{1}{2}\text{Br}_2(l) + \text{H}_2\text{O}$	1.584	-0.75
$\text{BrO}_3^- + 6\text{H}^+ + 5e^- \rightleftharpoons \frac{1}{2}\text{Br}_2(l) + 3\text{H}_2\text{O}$	1.513	-0.419
$\text{Br}_2(aq) + 2e^- \rightleftharpoons 2\text{Br}^-$	1.098	-0.499
$\text{Br}_2(l) + 2e^- \rightleftharpoons 2\text{Br}^-$	1.078	-0.611
$\text{Br}_3^- + 2e^- \rightleftharpoons 3\text{Br}^-$	1.062	-0.512
$\text{BrO}^- + \text{H}_2\text{O} + 2e^- \rightleftharpoons \text{Br}^- + 2\text{OH}^-$	0.766	-0.94
$\text{BrO}_3^- + 3\text{H}_2\text{O} + 6e^- \rightleftharpoons \text{Br}^- + 6\text{OH}^-$	0.613	-1.287
Cadmium		
$\text{Cd}^{2+} + 2e^- + \text{Hg} \rightleftharpoons \text{Cd}(in\ Hg)$	-0.380	
$\text{Cd}^{2+} + 2e^- \rightleftharpoons \text{Cd}(s)$	-0.402	-0.029
$\text{Cd}(\text{C}_2\text{O}_4)(s) + 2e^- \rightleftharpoons \text{Cd}(s) + \text{C}_2\text{O}_4^{2-}$	-0.522	
$\text{Cd}(\text{C}_2\text{O}_4)_2^{2-} + 2e^- \rightleftharpoons \text{Cd}(s) + 2\text{C}_2\text{O}_4^{2-}$	-0.572	
$\text{Cd}(\text{NH}_3)_4^{2+} + 2e^- \rightleftharpoons \text{Cd}(s) + 4\text{NH}_3$	-0.613	
$\text{CdS}(s) + 2e^- \rightleftharpoons \text{Cd}(s) + \text{S}^{2-}$	-1.175	
Calcium		
$\text{Ca}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{CaH}_2(s)$	0.776	
$\text{Ca}^{2+} + 2e^- + \text{Hg} \rightleftharpoons \text{Ca}(in\ Hg)$	-2.003	
$\text{Ca}^{2+} + 2e^- \rightleftharpoons \text{Ca}(s)$	-2.868	-0.186

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

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

Reaction	E° (volts)	dE°/dT (mV/K)											
$\text{Ca}(\text{acetate})^+ + 2e^- \rightleftharpoons \text{Ca}(s) + \text{acetate}^-$	-2.891												
$\text{CaSO}_4(s) + 2e^- \rightleftharpoons \text{Ca}(s) + \text{SO}_4^{2-}$	-2.936												
$\text{Ca}(\text{malonate})(s) + 2e^- \rightleftharpoons \text{Ca}(s) + \text{malonate}^{2-}$	-3.608												
Carbon													
$\text{C}_2\text{H}_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{C}_2\text{H}_4(g)$	0.731												
$\text{O}=\text{C}_6\text{H}_4=\text{O} + 2\text{H}^+ + 2e^- \rightleftharpoons \text{HO}-\text{C}_6\text{H}_4-\text{OH}$	0.700												
$\text{CH}_3\text{OH} + 2\text{H}^+ + 2e^- \rightleftharpoons \text{CH}_4(g) + \text{H}_2\text{O}$	0.583	-0.039											
Dehydroascorbic acid + $2\text{H}^+ + 2e^- \rightleftharpoons$ ascorbic acid + H_2O	0.390												
$(\text{CN})_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons 2\text{HCN}(aq)$	0.373												
$\text{H}_2\text{CO} + 2\text{H}^+ + 2e^- \rightleftharpoons \text{CH}_3\text{OH}$	0.237	-0.51											
$\text{C}(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{CH}_4(g)$	0.131 5	-0.209 2											
$\text{HCO}_2\text{H} + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{CO} + \text{H}_2\text{O}$	-0.029	-0.63											
$\text{CO}_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{CO}(g) + \text{H}_2\text{O}$	-0.103 8	-0.397 7											
$\text{CO}_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{HCO}_2\text{H}$	-0.114	-0.94											
$2\text{CO}_2(g) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{C}_2\text{O}_4$	-0.432	-1.76											
Cerium													
$\text{Ce}^{4+} + e^- \rightleftharpoons \text{Ce}^{3+}$	<table border="0"> <tr><td rowspan="5" style="font-size: 3em; vertical-align: middle;">{</td><td>1.72</td><td></td></tr> <tr><td>1.70</td><td>1 F HClO₄</td></tr> <tr><td>1.44</td><td>1 F H₂SO₄</td></tr> <tr><td>1.61</td><td>1 F HNO₃</td></tr> <tr><td>1.47</td><td>1 F HCl</td></tr> </table>	{	1.72		1.70	1 F HClO ₄	1.44	1 F H ₂ SO ₄	1.61	1 F HNO ₃	1.47	1 F HCl	1.54
{	1.72												
	1.70		1 F HClO ₄										
	1.44		1 F H ₂ SO ₄										
	1.61		1 F HNO ₃										
	1.47	1 F HCl											
$\text{Ce}^{3+} + 3e^- \rightleftharpoons \text{Ce}(s)$	-2.336	0.280											
Cesium													
$\text{Cs}^+ + e^- + \text{Hg} \rightleftharpoons \text{Cs}(in \text{Hg})$	-1.950												
$\text{Cs}^+ + e^- \rightleftharpoons \text{Cs}(s)$	-3.026	-1.172											
Chlorine													
$\text{HClO}_2 + 2\text{H}^+ + 2e^- \rightleftharpoons \text{HOCl} + \text{H}_2\text{O}$	1.674	0.55											
$\text{HClO} + \text{H}^+ + e^- \rightleftharpoons \frac{1}{2}\text{Cl}_2(g) + \text{H}_2\text{O}$	1.630	-0.27											
$\text{ClO}_3^- + 6\text{H}^+ + 5e^- \rightleftharpoons \frac{1}{2}\text{Cl}_2(g) + 3\text{H}_2\text{O}$	1.458	-0.347											
$\text{Cl}_2(aq) + 2e^- \rightleftharpoons 2\text{Cl}^-$	1.396	-0.72											
$\text{Cl}_2(g) + 2e^- \rightleftharpoons 2\text{Cl}^-$	1.360 4	-1.248											
$\text{ClO}_4^- + 2\text{H}^+ + 2e^- \rightleftharpoons \text{ClO}_3^- + \text{H}_2\text{O}$	1.226	-0.416											
$\text{ClO}_3^- + 3\text{H}^+ + 2e^- \rightleftharpoons \text{HClO}_2 + \text{H}_2\text{O}$	1.157	-0.180											
$\text{ClO}_3^- + 2\text{H}^+ + e^- \rightleftharpoons \text{ClO}_2 + \text{H}_2\text{O}$	1.130	0.074											
$\text{ClO}_2 + e^- \rightleftharpoons \text{ClO}_2^-$	1.068	-1.335											
Chromium													
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6e^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	1.36	-1.32											
$\text{CrO}_4^{2-} + 4\text{H}_2\text{O} + 3e^- \rightleftharpoons \text{Cr}(\text{OH})_3(s, \text{hydrated}) + 5\text{OH}^-$	-0.12	-1.62											
$\text{Cr}^{3+} + e^- \rightleftharpoons \text{Cr}^{2+}$	-0.42	1.4											
$\text{Cr}^{3+} + 3e^- \rightleftharpoons \text{Cr}(s)$	-0.74	0.44											
$\text{Cr}^{2+} + 2e^- \rightleftharpoons \text{Cr}(s)$	-0.89	-0.04											
Cobalt													
$\text{Co}^{3+} + e^- \rightleftharpoons \text{Co}^{2+}$	<table border="0"> <tr><td rowspan="4" style="font-size: 3em; vertical-align: middle;">{</td><td>1.92</td><td></td></tr> <tr><td>1.817</td><td>8 F H₂SO₄</td></tr> <tr><td>1.850</td><td>4 F HNO₃</td></tr> <tr><td>0.37</td><td>1 F NH₄NO₃</td></tr> </table>	{	1.92		1.817	8 F H ₂ SO ₄	1.850	4 F HNO ₃	0.37	1 F NH ₄ NO ₃	1.23		
{	1.92												
	1.817		8 F H ₂ SO ₄										
	1.850		4 F HNO ₃										
	0.37	1 F NH ₄ NO ₃											
$\text{Co}(\text{NH}_3)_5(\text{H}_2\text{O})^{3+} + e^- \rightleftharpoons \text{Co}(\text{NH}_3)_5(\text{H}_2\text{O})^{2+}$	0.1												
$\text{Co}(\text{NH}_3)_6^{3+} + e^- \rightleftharpoons \text{Co}(\text{NH}_3)_6^{2+}$	0.003	-0.04											
$\text{CoOH}^+ + \text{H}^+ + 2e^- \rightleftharpoons \text{Co}(s) + \text{H}_2\text{O}$	-0.282	0.065											
$\text{Co}^{2+} + 2e^- \rightleftharpoons \text{Co}(s)$	-0.746	-1.02											
$\text{Co}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Co}(s) + 2\text{OH}^-$													
Copper													
$\text{Cu}^+ + e^- \rightleftharpoons \text{Cu}(s)$	0.518	-0.754											
$\text{Cu}^{2+} + 2e^- \rightleftharpoons \text{Cu}(s)$	0.339	0.011											
$\text{Cu}^{2+} + e^- \rightleftharpoons \text{Cu}^+$	0.161	0.776											
$\text{CuCl}(s) + e^- \rightleftharpoons \text{Cu}(s) + \text{Cl}^-$	0.137												
$\text{Cu}(\text{IO}_3)_2(s) + 2e^- \rightleftharpoons \text{Cu}(s) + 2\text{IO}_3^-$	-0.079												
$\text{Cu}(\text{ethylenediamine})_2^+ + e^- \rightleftharpoons \text{Cu}(s) + 2 \text{ ethylenediamine}$	-0.119												
$\text{CuI}(s) + e^- \rightleftharpoons \text{Cu}(s) + \text{I}^-$	-0.185												
$\text{Cu}(\text{EDTA})^{2-} + 2e^- \rightleftharpoons \text{Cu}(s) + \text{EDTA}^{4-}$	-0.216												
$\text{Cu}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Cu}(s) + 2\text{OH}^-$	-0.222												
$\text{Cu}(\text{CN})_2 + e^- \rightleftharpoons \text{Cu}(s) + 2\text{CN}^-$	-0.429												
$\text{CuCN}(s) + e^- \rightleftharpoons \text{Cu}(s) + \text{CN}^-$	-0.639												

(Continued)

Reaction	E° (volts)	dE°/dT (mV/K)
Dysprosium		
$\text{Dy}^{3+} + 3e^- \rightleftharpoons \text{Dy}(s)$	-2.295	0.373
Erbium		
$\text{Er}^{3+} + 3e^- \rightleftharpoons \text{Er}(s)$	-2.331	0.388
Europium		
$\text{Eu}^{3+} + e^- \rightleftharpoons \text{Eu}^{2+}$	-0.35	1.53
$\text{Eu}^{3+} + 3e^- \rightleftharpoons \text{Eu}(s)$	-1.991	0.338
$\text{Eu}^{2+} + 2e^- \rightleftharpoons \text{Eu}(s)$	-2.812	-0.26
Fluorine		
$\text{F}_2(g) + 2e^- \rightleftharpoons 2\text{F}^-$	2.890	-1.870
$\text{F}_2\text{O}(g) + 2\text{H}^+ + 4e^- \rightleftharpoons 2\text{F}^- + \text{H}_2\text{O}$	2.168	-1.208
Gadolinium		
$\text{Gd}^{3+} + 3e^- \rightleftharpoons \text{Gd}(s)$	-2.279	0.315
Gallium		
$\text{Ga}^{3+} + 3e^- \rightleftharpoons \text{Ga}(s)$	-0.549	0.61
$\text{GaOOH}(s) + \text{H}_2\text{O} + 3e^- \rightleftharpoons \text{Ga}(s) + 3\text{OH}^-$	-1.320	-1.08
Germanium		
$\text{Ge}^{2+} + 2e^- \rightleftharpoons \text{Ge}(s)$	0.1	
$\text{H}_4\text{GeO}_4 + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Ge}(s) + 4\text{H}_2\text{O}$	-0.039	-0.429
Gold		
$\text{Au}^+ + e^- \rightleftharpoons \text{Au}(s)$	1.69	-1.1
$\text{Au}^{3+} + 2e^- \rightleftharpoons \text{Au}^+$	1.41	
$\text{AuCl}_2^- + e^- \rightleftharpoons \text{Au}(s) + 2\text{Cl}^-$	1.154	
$\text{AuCl}_4^- + 2e^- \rightleftharpoons \text{AuCl}_2^- + 2\text{Cl}^-$	0.926	
Hafnium		
$\text{Hf}^{4+} + 4e^- \rightleftharpoons \text{Hf}(s)$	-1.55	0.68
$\text{HfO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Hf}(s) + 2\text{H}_2\text{O}$	-1.591	-0.355
Holmium		
$\text{Ho}^{3+} + 3e^- \rightleftharpoons \text{Ho}(s)$	-2.33	0.371
Hydrogen		
$2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2(g)$	0.000 0	0
$\text{H}_2\text{O} + e^- \rightleftharpoons \frac{1}{2}\text{H}_2(g) + \text{OH}^-$	-0.828 0	-0.836 0
Indium		
$\text{In}^{3+} + 3e^- + \text{Hg} \rightleftharpoons \text{In}(in\ Hg)$	-0.313	
$\text{In}^{3+} + 3e^- \rightleftharpoons \text{In}(s)$	-0.338	0.42
$\text{In}^{3+} + 2e^- \rightleftharpoons \text{In}^+$	-0.444	
$\text{In}(\text{OH})_3(s) + 3e^- \rightleftharpoons \text{In}(s) + 3\text{OH}^-$	-0.99	-0.95
Iodine		
$\text{IO}_4^- + 2\text{H}^+ + 2e^- \rightleftharpoons \text{IO}_3^- + \text{H}_2\text{O}$	1.589	-0.85
$\text{H}_5\text{IO}_6 + 2\text{H}^+ + 2e^- \rightleftharpoons \text{HIO}_3 + 3\text{H}_2\text{O}$	1.567	-0.12
$\text{HOI} + \text{H}^+ + e^- \rightleftharpoons \frac{1}{2}\text{I}_2(s) + \text{H}_2\text{O}$	1.430	-0.339
$\text{ICl}_3(s) + 3e^- \rightleftharpoons \frac{1}{2}\text{I}_2(s) + 3\text{Cl}^-$	1.28	
$\text{ICl}(s) + e^- \rightleftharpoons \frac{1}{2}\text{I}_2(s) + \text{Cl}^-$	1.22	
$\text{IO}_3^- + 6\text{H}^+ + 5e^- \rightleftharpoons \frac{1}{2}\text{I}_2(s) + 3\text{H}_2\text{O}$	1.210	-0.367
$\text{IO}_3^- + 5\text{H}^+ + 4e^- \rightleftharpoons \text{HOI} + 2\text{H}_2\text{O}$	1.154	-0.374
$\text{I}_2(aq) + 2e^- \rightleftharpoons 2\text{I}^-$	0.620	-0.234
$\text{I}_2(s) + 2e^- \rightleftharpoons 2\text{I}^-$	0.535	-0.125
$\text{I}_3^- + 2e^- \rightleftharpoons 3\text{I}^-$	0.535	-0.186
$\text{IO}_3^- + 3\text{H}_2\text{O} + 6e^- \rightleftharpoons \text{I}^- + 6\text{OH}^-$	0.269	-1.163
Iridium		
$\text{IrCl}_6^{2-} + e^- \rightleftharpoons \text{IrCl}_6^{3-}$	1.026	1 F HCl
$\text{IrBr}_6^{2-} + e^- \rightleftharpoons \text{IrBr}_6^{3-}$	0.947	2 F NaBr
$\text{IrCl}_6^{2-} + 4e^- \rightleftharpoons \text{Ir}(s) + 6\text{Cl}^-$	0.835	
$\text{IrO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Ir}(s) + 2\text{H}_2\text{O}$	0.73	
$\text{Ir}_3^{2+} + e^- \rightleftharpoons \text{Ir}_3^{3+}$	0.485	1 F KI
Iron		
$\text{Fe}(\text{phenanthroline})_3^{3+} + e^- \rightleftharpoons \text{Fe}(\text{phenanthroline})_3^{2+}$	1.147	
$\text{Fe}(\text{bipyridyl})_3^{3+} + e^- \rightleftharpoons \text{Fe}(\text{bipyridyl})_3^{2+}$	1.120	
$\text{FeOH}^{2+} + \text{H}^+ + e^- \rightleftharpoons \text{Fe}^{2+} + \text{H}_2\text{O}$	0.900	0.096
$\text{FeO}_4^{2-} + 3\text{H}_2\text{O} + 3e^- \rightleftharpoons \text{FeOOH}(s) + 5\text{OH}^-$	0.80	-1.59
	0.771	1.175
$\text{Fe}^{3+} + e^- \rightleftharpoons \text{Fe}^{2+}$	0.732	1 F HCl
	0.767	1 F HClO ₄
	0.746	1 F HNO ₃
	0.68	1 F H ₂ SO ₄

Reaction	E° (volts)	dE°/dT (mV/K)
$\text{FeOOH}(s) + 3\text{H}^+ + e^- \rightleftharpoons \text{Fe}^{2+} + 2\text{H}_2\text{O}$	0.74	-1.05
Ferricinium ⁺ + e ⁻ ⇌ ferrocene	0.400	
$\text{Fe}(\text{CN})_6^{3-} + e^- \rightleftharpoons \text{Fe}(\text{CN})_6^{4-}$	0.356	
$\text{Fe}(\text{glutamate})^{3+} + e^- \rightleftharpoons \text{Fe}(\text{glutamate})^{2+}$	0.240	
$\text{FeOH}^+ + \text{H}^+ + 2e^- \rightleftharpoons \text{Fe}(s) + \text{H}_2\text{O}$	-0.16	0.07
$\text{Fe}^{2+} + 2e^- \rightleftharpoons \text{Fe}(s)$	-0.44	0.07
$\text{FeCO}_3(s) + 2e^- \rightleftharpoons \text{Fe}(s) + \text{CO}_3^{2-}$	-0.756	-1.293
Lanthanum		
$\text{La}^{3+} + 3e^- \rightleftharpoons \text{La}(s)$	-2.379	0.242
$\text{La}(\text{succinate})^+ + 3e^- \rightleftharpoons \text{La}(s) + \text{succinate}^{2-}$	-2.601	
Lead		
$\text{Pb}^{4+} + 2e^- \rightleftharpoons \text{Pb}^{2+}$	1.69	1 F HNO ₃
$\text{PbO}_2(s) + 4\text{H}^+ + \text{SO}_4^{2-} + 2e^- \rightleftharpoons \text{PbSO}_4(s) + 2\text{H}_2\text{O}$	1.685	
$\text{PbO}_2(s) + 4\text{H}^+ + 2e^- \rightleftharpoons \text{Pb}^{2+} + 2\text{H}_2\text{O}$	1.458	-0.253
$3\text{PbO}_2(s) + 2\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{Pb}_3\text{O}_4(s) + 4\text{OH}^-$	0.269	-1.136
$\text{Pb}_3\text{O}_4(s) + \text{H}_2\text{O} + 2e^- \rightleftharpoons 3\text{PbO}(s, \text{red}) + 2\text{OH}^-$	0.224	-1.211
$\text{Pb}_3\text{O}_4(s) + \text{H}_2\text{O} + 2e^- \rightleftharpoons 3\text{PbO}(s, \text{yellow}) + 2\text{OH}^-$	0.207	-1.177
$\text{Pb}^{2+} + 2e^- \rightleftharpoons \text{Pb}(s)$	-0.126	-0.395
$\text{PbF}_2(s) + 2e^- \rightleftharpoons \text{Pb}(s) + 2\text{F}^-$	-0.350	
$\text{PbSO}_4(s) + 2e^- \rightleftharpoons \text{Pb}(s) + \text{SO}_4^{2-}$	-0.355	
Lithium		
$\text{Li}^+ + e^- + \text{Hg} \rightleftharpoons \text{Li}(\text{in Hg})$	-2.195	
$\text{Li}^+ + e^- \rightleftharpoons \text{Li}(s)$	-3.040	-0.514
Lutetium		
$\text{Lu}^{3+} + 3e^- \rightleftharpoons \text{Lu}(s)$	-2.28	0.412
Magnesium		
$\text{Mg}^{2+} + 2e^- + \text{Hg} \rightleftharpoons \text{Mg}(\text{in Hg})$	-1.980	
$\text{Mg}(\text{OH})^+ + \text{H}^+ + 2e^- \rightleftharpoons \text{Mg}(s) + \text{H}_2\text{O}$	-2.022	0.25
$\text{Mg}^{2+} + 2e^- \rightleftharpoons \text{Mg}(s)$	-2.360	0.199
$\text{Mg}(\text{C}_2\text{O}_4)(s) + 2e^- \rightleftharpoons \text{Mg}(s) + \text{C}_2\text{O}_4^{2-}$	-2.493	
$\text{Mg}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Mg}(s) + 2\text{OH}^-$	-2.690	-0.946
Manganese		
$\text{MnO}_4^- + 4\text{H}^+ + 3e^- \rightleftharpoons \text{MnO}_2(s) + 2\text{H}_2\text{O}$	1.692	-0.671
$\text{Mn}^{3+} + e^- \rightleftharpoons \text{Mn}^{2+}$	1.56	1.8
$\text{MnO}_4^- + 8\text{H}^+ + 5e^- \rightleftharpoons \text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.507	-0.646
$\text{Mn}_2\text{O}_3(s) + 6\text{H}^+ + 2e^- \rightleftharpoons 2\text{Mn}^{2+} + 3\text{H}_2\text{O}$	1.485	-0.926
$\text{MnO}_2(s) + 4\text{H}^+ + 2e^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O}$	1.230	-0.609
$\text{Mn}(\text{EDTA})^- + e^- \rightleftharpoons \text{Mn}(\text{EDTA})^{2-}$	0.825	-1.10
$\text{MnO}_4^- + e^- \rightleftharpoons \text{MnO}_4^{2-}$	0.56	-2.05
$3\text{Mn}_2\text{O}_3(s) + \text{H}_2\text{O} + 2e^- \rightleftharpoons 2\text{Mn}_3\text{O}_4(s) + 2\text{OH}^-$	0.002	-1.256
$\text{Mn}_3\text{O}_4(s) + 4\text{H}_2\text{O} + 2e^- \rightleftharpoons 3\text{Mn}(\text{OH})_2(s) + 2\text{OH}^-$	-0.352	-1.61
$\text{Mn}^{2+} + 2e^- \rightleftharpoons \text{Mn}(s)$	-1.182	-1.129
$\text{Mn}(\text{OH})_2(s) + 2e^- \rightleftharpoons \text{Mn}(s) + 2\text{OH}^-$	-1.565	-1.10
Mercury		
$2\text{Hg}^{2+} + 2e^- \rightleftharpoons \text{Hg}_2^{2+}$	0.908	0.095
$\text{Hg}_2^{2+} + 2e^- \rightleftharpoons \text{Hg}(l)$	0.852	-0.116
$\text{Hg}_2^{2+} + 2e^- \rightleftharpoons 2\text{Hg}(l)$	0.796	-0.327
$\text{Hg}_2\text{SO}_4(s) + 2e^- \rightleftharpoons 2\text{Hg}(l) + \text{SO}_4^{2-}$	0.614	
$\text{Hg}_2\text{Cl}_2(s) + 2e^- \rightleftharpoons 2\text{Hg}(l) + 2\text{Cl}^-$	0.268	
$\text{Hg}(\text{OH})_3^- + 2e^- \rightleftharpoons \text{Hg}(l) + 3\text{OH}^-$	0.231	
$\text{Hg}(\text{OH})_2 + 2e^- \rightleftharpoons \text{Hg}(l) + 2\text{OH}^-$	0.206	-1.24
$\text{Hg}_2\text{Br}_2(s) + 2e^- \rightleftharpoons 2\text{Hg}(l) + 2\text{Br}^-$	0.140	
$\text{HgO}(s, \text{yellow}) + \text{H}_2\text{O} + 2e^- \rightleftharpoons \text{Hg}(l) + 2\text{OH}^-$	0.098 3	-1.125
$\text{HgO}(s, \text{red}) + \text{H}_2\text{O} + 2e^- \rightleftharpoons \text{Hg}(l) + 2\text{OH}^-$	0.097 7	-1.120 6
Molybdenum		
$\text{MoO}_4^{2-} + 2\text{H}_2\text{O} + 2e^- \rightleftharpoons \text{MoO}_2(s) + 4\text{OH}^-$	-0.818	-1.69
$\text{MoO}_4^{2-} + 4\text{H}_2\text{O} + 6e^- \rightleftharpoons \text{Mo}(s) + 8\text{OH}^-$	-0.926	-1.36
$\text{MoO}_2(s) + 2\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{Mo}(s) + 4\text{OH}^-$	-0.980	-1.196
Neodymium		
$\text{Nd}^{3+} + 3e^- \rightleftharpoons \text{Nd}(s)$	-2.323	0.282
Neptunium		
$\text{NpO}_3^+ + 2\text{H}^+ + e^- \rightleftharpoons \text{NpO}_2^{2+} + \text{H}_2\text{O}$	2.04	
$\text{NpO}_2^{2+} + e^- \rightleftharpoons \text{NpO}_2^+$	1.236	0.058

(Continued)

Reaction	E° (volts)	dE°/dT (mV/K)
$\text{NpO}_2^+ + 4\text{H}^+ + \text{e}^- \rightleftharpoons \text{Np}^{4+} + 2\text{H}_2\text{O}$	0.567	-3.30
$\text{Np}^{4+} + \text{e}^- \rightleftharpoons \text{Np}^{3+}$	0.157	1.53
$\text{Np}^{3+} + 3\text{e}^- \rightleftharpoons \text{Np}(s)$	-1.768	0.18
Nickel		
$\text{NiOOH}(s) + 3\text{H}^+ + \text{e}^- \rightleftharpoons \text{Ni}^{2+} + 2\text{H}_2\text{O}$	2.05	-1.17
$\text{Ni}^{2+} + 2\text{e}^- \rightleftharpoons \text{Ni}(s)$	-0.236	0.146
$\text{Ni}(\text{CN})_4^{2-} + \text{e}^- \rightleftharpoons \text{Ni}(\text{CN})_3^- + \text{CN}^-$	-0.401	
$\text{Ni}(\text{OH})_2(s) + 2\text{e}^- \rightleftharpoons \text{Ni}(s) + 2\text{OH}^-$	-0.714	-1.02
Niobium		
$\frac{1}{2}\text{Nb}_2\text{O}_5(s) + \text{H}^+ + \text{e}^- \rightleftharpoons \text{NbO}_2(s) + \frac{1}{2}\text{H}_2\text{O}$	-0.248	-0.460
$\frac{1}{2}\text{Nb}_2\text{O}_5(s) + 5\text{H}^+ + 5\text{e}^- \rightleftharpoons \text{Nb}(s) + \frac{5}{2}\text{H}_2\text{O}$	-0.601	-0.381
$\text{NbO}_2(s) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{NbO}(s) + \text{H}_2\text{O}$	-0.646	-0.347
$\text{NbO}_2(s) + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons \text{Nb}(s) + 2\text{H}_2\text{O}$	-0.690	-0.361
Nitrogen		
$\text{HN}_3 + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{N}_2(g) + \text{NH}_4^+$	2.079	0.147
$\text{N}_2\text{O}(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{N}_2(g) + \text{H}_2\text{O}$	1.769	-0.461
$2\text{NO}(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{N}_2\text{O}(g) + \text{H}_2\text{O}$	1.587	-1.359
$\text{NO}^+ + \text{e}^- \rightleftharpoons \text{NO}(g)$	1.46	
$2\text{NH}_3\text{OH}^+ + \text{H}^+ + 2\text{e}^- \rightleftharpoons \text{N}_2\text{H}_5^+ + 2\text{H}_2\text{O}$	1.40	-0.60
$\text{NH}_3\text{OH}^+ + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{NH}_4^+ + \text{H}_2\text{O}$	1.33	-0.44
$\text{N}_2\text{H}_5^+ + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons 2\text{NH}_4^+$	1.250	-0.28
$\text{HNO}_2 + \text{H}^+ + \text{e}^- \rightleftharpoons \text{NO}(g) + \text{H}_2\text{O}$	0.984	0.649
$\text{NO}_2^- + 4\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{NO}(g) + 2\text{H}_2\text{O}$	0.955	0.028
$\text{NO}_3^- + 3\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{HNO}_2 + \text{H}_2\text{O}$	0.940	-0.282
$\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightleftharpoons \frac{1}{2}\text{N}_2\text{O}_4(g) + \text{H}_2\text{O}$	0.798	0.107
$\text{N}_2(g) + 8\text{H}^+ + 6\text{e}^- \rightleftharpoons 2\text{NH}_4^+$	0.274	-0.616
$\text{N}_2(g) + 5\text{H}^+ + 4\text{e}^- \rightleftharpoons \text{N}_2\text{H}_5^+$	-0.214	-0.78
$\text{N}_2(g) + 2\text{H}_2\text{O} + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons 2\text{NH}_3\text{OH}^+$	-1.83	-0.96
$\frac{1}{2}\text{N}_2(g) + \text{H}^+ + \text{e}^- \rightleftharpoons \text{HN}_3$	-3.334	-2.141
Osmium		
$\text{OsO}_4(s) + 8\text{H}^+ + 8\text{e}^- \rightleftharpoons \text{Os}(s) + 4\text{H}_2\text{O}$	0.834	-0.458
$\text{OsCl}_6^{2-} + \text{e}^- \rightleftharpoons \text{OsCl}_6^{3-}$	0.85	1 F HCl
Oxygen		
$\text{OH} + \text{H}^+ + \text{e}^- \rightleftharpoons \text{H}_2\text{O}$	2.56	-1.0
$\text{O}(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}$	2.430	-1.148
$\text{O}_3(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{O}_2(g) + \text{H}_2\text{O}$	2.075	-0.489
$\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$	1.763	-0.698
$\text{HO}_2 + \text{H}^+ + \text{e}^- \rightleftharpoons \text{H}_2\text{O}_2$	1.44	-0.7
$\frac{1}{2}\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}$	1.229	-0.845
$\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2$	0.695	-0.993
$\text{O}_2(g) + \text{H}^+ + \text{e}^- \rightleftharpoons \text{HO}_2$	-0.05	-1.3
Palladium		
$\text{Pd}^{2+} + 2\text{e}^- \rightleftharpoons \text{Pd}(s)$	0.915	0.12
$\text{PdO}(s) + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Pd}(s) + \text{H}_2\text{O}$	0.79	-0.33
$\text{PdCl}_4^{2-} + 2\text{e}^- \rightleftharpoons \text{Pd}(s) + 6\text{Cl}^-$	0.615	
$\text{PdO}_2(s) + \text{H}_2\text{O} + 2\text{e}^- \rightleftharpoons \text{PdO}(s) + 2\text{OH}^-$	0.64	-1.2
Phosphorus		
$\frac{1}{4}\text{P}_4(s, \text{white}) + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{PH}_3(g)$	-0.046	-0.093
$\frac{1}{4}\text{P}_4(s, \text{red}) + 3\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{PH}_3(g)$	-0.088	-0.030
$\text{H}_3\text{PO}_4 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_3\text{PO}_3 + \text{H}_2\text{O}$	-0.30	-0.36
$\text{H}_3\text{PO}_4 + 5\text{H}^+ + 5\text{e}^- \rightleftharpoons \frac{1}{4}\text{P}_4(s, \text{white}) + 4\text{H}_2\text{O}$	-0.402	-0.340
$\text{H}_3\text{PO}_3 + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_3\text{PO}_2 + \text{H}_2\text{O}$	-0.48	-0.37
$\text{H}_3\text{PO}_2 + \text{H}^+ + \text{e}^- \rightleftharpoons \frac{1}{4}\text{P}_4(s) + 2\text{H}_2\text{O}$	-0.51	
Platinum		
$\text{Pt}^{2+} + 2\text{e}^- \rightleftharpoons \text{Pt}(s)$	1.18	-0.05
$\text{PtO}_2(s) + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons \text{Pt}(s) + 2\text{H}_2\text{O}$	0.92	-0.36
$\text{PtCl}_4^{2-} + 2\text{e}^- \rightleftharpoons \text{Pt}(s) + 4\text{Cl}^-$	0.755	
$\text{PtCl}_6^{2-} + 2\text{e}^- \rightleftharpoons \text{PtCl}_4^{2-} + 2\text{Cl}^-$	0.68	
Plutonium		
$\text{PuO}_2^+ + \text{e}^- \rightleftharpoons \text{PuO}_2(s)$	1.585	0.39
$\text{PuO}_2^+ + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Pu}^{4+} + 2\text{H}_2\text{O}$	1.000	-1.615
$\text{Pu}^{4+} + \text{e}^- \rightleftharpoons \text{Pu}^{3+}$	1.006	1.441
$\text{PuO}_2^+ + \text{e}^- \rightleftharpoons \text{PuO}_2^0$	0.966	0.03
$\text{PuO}_2(s) + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons \text{Pu}(s) + 2\text{H}_2\text{O}$	-1.369	-0.38
$\text{Pu}^{3+} + 3\text{e}^- \rightleftharpoons \text{Pu}(s)$	-1.978	0.23

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

(Continued)

Reaction	E° (volts)	dE°/dT (mV/K)
Strontium		
$\text{Sr}^{2+} + 2e^- \rightleftharpoons \text{Sr}(s)$	-2.889	-0.237
Sulfur		
$\text{S}_2\text{O}_8^{2-} + 2e^- \rightleftharpoons 2\text{SO}_4^{2-}$	2.01	
$\text{S}_2\text{O}_8^{2-} + 4\text{H}^+ + 2e^- \rightleftharpoons 2\text{H}_2\text{SO}_4$	0.57	
$4\text{SO}_2 + 4\text{H}^+ + 6e^- \rightleftharpoons \text{S}_4\text{O}_6^{2-} + 2\text{H}_2\text{O}$	0.539	-1.11
$\text{SO}_2 + 4\text{H}^+ + 4e^- \rightleftharpoons \text{S}(s) + 2\text{H}_2\text{O}$	0.450	-0.652
$2\text{H}_2\text{SO}_3 + 2\text{H}^+ + 4e^- \rightleftharpoons \text{S}_2\text{O}_3^{2-} + 3\text{H}_2\text{O}$	0.40	
$\text{S}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{S}(g)$	0.174	0.224
$\text{S}(s) + 2\text{H}^+ + 2e^- \rightleftharpoons \text{H}_2\text{S}(aq)$	0.144	-0.21
$\text{S}_4\text{O}_6^{2-} + 2\text{H}^+ + 2e^- \rightleftharpoons 2\text{HS}_2\text{O}_3^-$	0.10	-0.23
$5\text{S}(s) + 2e^- \rightleftharpoons \text{S}_5^{2-}$	-0.340	
$\text{S}(s) + 2e^- \rightleftharpoons \text{S}^{2-}$	-0.476	-0.925
$2\text{S}(s) + 2e^- \rightleftharpoons \text{S}_2^{2-}$	-0.50	-1.16
$2\text{SO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{S}_2\text{O}_3^{2-} + 6\text{OH}^-$	-0.566	-1.06
$\text{SO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{S}(s) + 6\text{OH}^-$	-0.659	-1.23
$\text{SO}_4^{2-} + 4\text{H}_2\text{O} + 6e^- \rightleftharpoons \text{S}(s) + 8\text{OH}^-$	-0.751	-1.288
$\text{SO}_3^{2-} + \text{H}_2\text{O} + 2e^- \rightleftharpoons \text{SO}_3^{2-} + 2\text{OH}^-$	-0.936	-1.41
$2\text{SO}_3^{2-} + 2\text{H}_2\text{O} + 2e^- \rightleftharpoons \text{S}_2\text{O}_4^{2-} + 4\text{OH}^-$	-1.130	-0.85
$2\text{SO}_4^{2-} + 2\text{H}_2\text{O} + 2e^- \rightleftharpoons \text{S}_2\text{O}_6^{2-} + 4\text{OH}^-$	-1.71	-1.00
Tantalum		
$\text{Ta}_2\text{O}_5(s) + 10\text{H}^+ + 10e^- \rightleftharpoons 2\text{Ta}(s) + 5\text{H}_2\text{O}$	-0.752	-0.377
Technetium		
$\text{TcO}_4^- + 2\text{H}_2\text{O} + 3e^- \rightleftharpoons \text{TcO}_2(s) + 4\text{OH}^-$	-0.366	-1.82
$\text{TcO}_4^- + 4\text{H}_2\text{O} + 7e^- \rightleftharpoons \text{Tc}(s) + 8\text{OH}^-$	-0.474	-1.46
Tellurium		
$\text{TeO}_3^{2-} + 3\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{Te}(s) + 6\text{OH}^-$	-0.47	-1.39
$2\text{Te}(s) + 2e^- \rightleftharpoons \text{Te}_2^{2-}$	-0.84	
$\text{Te}(s) + 2e^- \rightleftharpoons \text{Te}^{2-}$	-0.90	-1.0
Terbium		
$\text{Tb}^{4+} + e^- \rightleftharpoons \text{Tb}^{3+}$	3.1	1.5
$\text{Tb}^{3+} + 3e^- \rightleftharpoons \text{Tb}(s)$	-2.28	0.350
Thallium		
$\text{Tl}^{3+} + 2e^- \rightleftharpoons \text{Tl}^+$	1.280	0.97
	0.77	1 F HCl
	1.22	1 F H ₂ SO ₄
	-1.23	1 F HNO ₃
	-1.26	1 F HClO ₄
$\text{Tl}^+ + e^- + \text{Hg} \rightleftharpoons \text{Tl}(in\ Hg)$	-0.294	
$\text{Tl}^+ + e^- \rightleftharpoons \text{Tl}(s)$	-0.336	-1.312
$\text{TlCl}(s) + e^- \rightleftharpoons \text{Tl}(s) + \text{Cl}^-$	-0.557	
Thorium		
$\text{Th}^{4+} + 4e^- \rightleftharpoons \text{Th}(s)$	-1.826	0.557
Thulium		
$\text{Tm}^{3+} + 3e^- \rightleftharpoons \text{Tm}(s)$	-2.319	0.394
Tin		
$\text{Sn}(\text{OH})_3^+ + 3\text{H}^+ + 2e^- \rightleftharpoons \text{Sn}^{2+} + 3\text{H}_2\text{O}$	0.142	
$\text{Sn}^{4+} + 2e^- \rightleftharpoons \text{Sn}^{2+}$	0.139	1 F HCl
$\text{SnO}_2(s) + 4\text{H}^+ + 2e^- \rightleftharpoons \text{Sn}^{2+} + 2\text{H}_2\text{O}$	-0.094	-0.31
$\text{Sn}^{2+} + 2e^- \rightleftharpoons \text{Sn}(s)$	-0.141	-0.32
$\text{SnF}_6^{2-} + 4e^- \rightleftharpoons \text{Sn}(s) + 6\text{F}^-$	-0.25	
$\text{Sn}(\text{OH})_6^{2-} + 2e^- \rightleftharpoons \text{Sn}(\text{OH})_3 + 3\text{OH}^-$	-0.93	
$\text{Sn}(s) + 4\text{H}_2\text{O} + 4e^- \rightleftharpoons \text{SnH}_4(g) + 4\text{OH}^-$	-1.316	-1.057
$\text{SnO}_2(s) + \text{H}_2\text{O} + 2e^- \rightleftharpoons \text{SnO}(s) + 2\text{OH}^-$	-0.961	-1.129
Titanium		
$\text{TiO}^{2+} + 2\text{H}^+ + e^- \rightleftharpoons \text{Ti}^{3+} + \text{H}_2\text{O}$	0.1	-0.6
$\text{Ti}^{3+} + e^- \rightleftharpoons \text{Ti}^{2+}$	-0.9	1.5
$\text{TiO}_2(s) + 4\text{H}^+ + 4e^- \rightleftharpoons \text{Ti}(s) + 2\text{H}_2\text{O}$	-1.076	0.365
$\text{TiF}_6^{2-} + 4e^- \rightleftharpoons \text{Ti}(s) + 6\text{F}^-$	-1.191	
$\text{Ti}^{2+} + 2e^- \rightleftharpoons \text{Ti}(s)$	-1.60	-0.16
Tungsten		
$\text{W}(\text{CN})_8^{3-} + e^- \rightleftharpoons \text{W}(\text{CN})_8^{4-}$	0.457	
$\text{W}^{6+} + e^- \rightleftharpoons \text{W}^{5+}$	0.26	12 F HCl
$\text{WO}_3(s) + 6\text{H}^+ + 6e^- \rightleftharpoons \text{W}(s) + 3\text{H}_2\text{O}$	-0.091	-0.389

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

General data and
fundamental
constants

Quantity	Symbol	Value
Speed of light	c	$2.99792458 \times 10^8 \text{ m s}^{-1}$
Elementary charge	e	$1.602177 \times 10^{-19} \text{ C}$
Faraday constant	$F = eN_A$	$9.6485 \times 10^4 \text{ C mol}^{-1}$
Boltzmann constant	k	$1.38066 \times 10^{-23} \text{ J K}^{-1}$
Gas constant	$R = kN_A$	$8.31451 \text{ J K}^{-1} \text{ mol}^{-1}$ $8.20578 \times 10^{-2} \text{ dm}^3 \text{ atm K}^{-1} \text{ mol}^{-1}$
Planck constant	h	$6.62608 \times 10^{-34} \text{ J s}$
	$\hbar = h/2\pi$	$1.05457 \times 10^{-35} \text{ J s}$
Avogadro constant	N_A	$6.02214 \times 10^{23} \text{ mol}^{-1}$
Atomic mass unit	u	$1.66054 \times 10^{-27} \text{ kg}$
Mass of electron	m_e	$9.10939 \times 10^{-31} \text{ kg}$
proton	m_p	$1.67262 \times 10^{-27} \text{ kg}$
neutron	m_n	$1.67493 \times 10^{-27} \text{ kg}$
Vacuum permeability	μ_0	$4\pi \times 10^{-7} \text{ J s}^2 \text{ C}^{-2} \text{ m}^{-1}$
Vacuum permittivity	$\epsilon_0 = 1/c^2 \mu_0$	$8.85418 \times 10^{-12} \text{ J}^{-1} \text{ C}^2 \text{ m}^{-1}$
	$\epsilon = \epsilon_0$	$1.11265 \times 10^{-10} \text{ J}^{-1} \text{ C}^2 \text{ m}^{-1}$
Bohr magneton	$\beta_B = e\hbar/2m_e$	$9.27402 \times 10^{-24} \text{ J T}^{-1}$
Nuclear magneton	$\beta_N = e\hbar/2m_p$	$5.05078 \times 10^{-27} \text{ J T}^{-1}$
Electron g value	g_e	2.00232
Bohr radius	$a_0 = 4\pi\epsilon_0\hbar^2/m_e e^2$	$5.29177 \times 10^{-11} \text{ m}$
Rydberg constant	$R_\infty = m_e e^4/8h^3 c$	$1.09737 \times 10^7 \text{ cm}^{-1}$
Fine structure constant	$\alpha = \mu_0 e^2 c/2h$	7.29735×10^{-3}
Gravitational constant	G	$6.67259 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Standard acceleration of free fall	g	9.80665 m s^{-2}

(Exact defined values)

f	p	n	μ	m	c	d	k	M	G	Prefixes
femto	pico	nano	micro	milli	centi	deci	kilo	mega	giga	
10^{-15}	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^3	10^6	10^9	

The Periodic Table of the Elements

1 H Hydrogen 1.00794																	2 He Helium 4.003														
3 Li Lithium 6.941	4 Be Beryllium 9.012182															5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797										
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050															13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948										
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80														
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29														
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)														
87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (262)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 (269)	111 (272)	112 (277)																				
																		58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
																		90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

1995 IUPAC masses and Approved Names from <http://www.chem.msu.ac.uk/ipac/ATW/>
 masses for 107-111 from C&EN, March 13, 1995, p. 35
 112 from <http://www.aui.de/~112e.html>