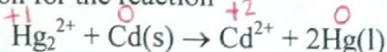


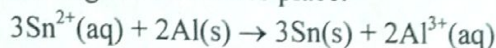
18 • Electrochemistry

anode (ox.) || cathode (red.)

1. Which of the following is the correct cell notation for the reaction



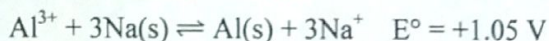
- a) $\text{Cd}^{2+} | \text{Cd} || \text{Hg}_2^{2+} | \text{Hg}$
 b) $\text{Cd}^{2+} | \text{Hg}_2^{2+} || \text{Cd} | \text{Hg}$
 c) $\text{Cd} | \text{Cd}^{2+} || \text{Hg}_2^{2+} | \text{Hg}$
 d) $\text{Cd}^{2+} | \text{Hg} || \text{Hg}_2^{2+} | \text{Cd}$
 e) $\text{Hg} | \text{Cd} || \text{Hg}_2^{2+} | \text{Cd}^{2+}$
2. Consider an electrochemical cell where the following reaction takes place:



Which of the following is the correct cell notation for this cell?

- a) $\text{Al} | \text{Al}^{3+} || \text{Sn}^{2+} | \text{Sn}$
 b) $\text{Al}^{3+} | \text{Al} || \text{Sn} | \text{Sn}^{2+}$
 c) $\text{Sn} | \text{Sn}^{2+} || \text{Al}^{3+} | \text{Al}$
 d) $\text{Sn} | \text{Al}^{3+} || \text{Al} | \text{Sn}^{2+}$
 e) $\text{Al} | \text{Sn}^{2+} || \text{Sn} | \text{Al}^{3+}$

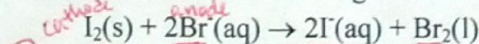
3. An early method of producing aluminum metal was the reaction of aluminum salts with sodium metal:



What is ΔG° for this reaction

- a) -304 kJ
 b) -101 kJ
 c) +101 kJ
 d) +202 kJ
 e) +304 kJ

4. Calculate ΔG for the following reaction:



- a) +105 kJ
 b) -105 kJ
 c) +312 kJ
 d) +52 kJ
 e) -312 kJ

5. If ΔG of the following reaction is -203 kJ, what is E° ? $2\text{Ag}^+(\text{aq}) + \text{Ni(s)} \rightarrow 2\text{Ag(s)} + \text{Ni}^{2+}(\text{aq})$

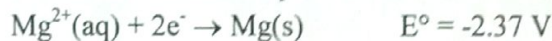
- a) -1.05 V
 b) +2.10 V
 c) +0.0011 V
 d) -0.011 V
 e) +1.05 V

$$\Delta G^\circ = -nFE^\circ$$

$$E^\circ = \frac{-\Delta G^\circ}{nF} = \frac{-(-203000 \text{ J})}{(2 \text{ mol e}^-)(96485 \text{ C/mol e}^-)} = +1.05 \text{ V}$$

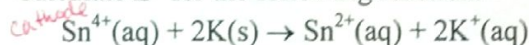
PRACTICE TEST

6. Given the two half reactions and their potentials, which net reaction is spontaneous?

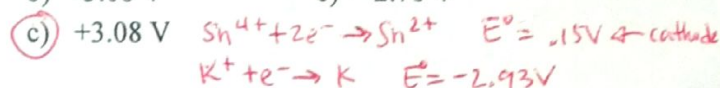


- a) $\text{Ni(s)} + \text{Mg}^{2+}(\text{aq}) \rightarrow \text{Mg(s)} + \text{Ni}^{2+}(\text{aq})$
 b) $\text{Ni}^{2+}(\text{aq}) + \text{Mg(s)} \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{Ni(s)}$
 c) $\text{Ni(s)} + \text{Mg(s)} \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{Ni}^{2+}(\text{aq})$
 d) $\text{Mg}^{2+}(\text{aq}) + \text{Ni}^{2+}(\text{aq}) \rightarrow \text{Mg(s)} + \text{Ni(s)}$
 e) $\text{Mg}^{2+}(\text{aq}) + \text{Mg(s)} \rightarrow \text{Ni(s)} + \text{Ni}^{2+}(\text{aq})$

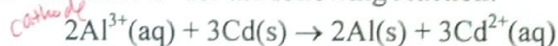
7. Calculate E° for the following reaction:



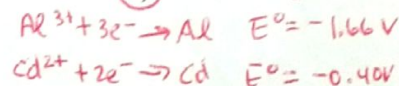
- a) +6.00 V
 b) -3.08 V
 c) +3.08 V
 d) +2.78 V
 e) -2.78 V



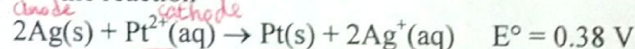
8. Calculate E° for the following reaction:



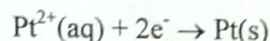
- a) -2.06 V
 b) +4.52 V
 c) +2.06 V
 d) -4.52 V
 e) -1.26 V (electrolytic)



9. Using data from the reduction potential table and the reaction



calculate the standard reduction potential of the half-reaction



- a) -1.18 V
 b) -0.40 V
 c) 0.40 V
 d) 1.18 V
 e) 2.00 V

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$$

$$0.38 \text{ V} = x - (-0.80) \quad x = 1.18 \text{ V}$$

10. An electrochemical cell of notation $\text{Pd} | \text{Pd}^{2+} || \text{Cu}^{2+} | \text{Cu}$ has an $E^\circ = -0.65 \text{ V}$. If we know that the standard reduction potential of Cu^{2+}/Cu is $E^\circ = 0.34 \text{ V}$, what is the standard reduction potential for Pd^{2+}/Pd ?

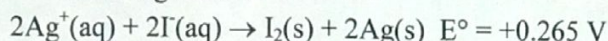
- a) -0.99 V
 b) -0.31 V
 c) +0.31 V
 d) 0.62 V
 e) +0.99 V

$$E^\circ_{\text{cell}} = E^\circ_{\text{cathode}} - E^\circ_{\text{anode}}$$

$$-0.65 = 0.34 - x$$

$$x = 0.99 \text{ V}$$

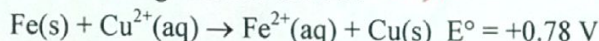
11. What is the equilibrium constant for the following reaction at 298 K?



- a) 2.99×10^4 d) 87.9
b) 9.04×10^8 e) 1.60×10^7
 c) 7.73×10^3

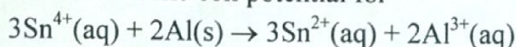
Use $\Delta G = -nFE$
 Then $\Delta G = -RT \ln K$ } solve for K

12. What is the equilibrium constant for the following reaction at 20°C? **293K**



- a) 2.3×10^{26} d) 1.8×10^{28}
b) 6.9×10^{26} e) 1.2×10^{-21}
 c) 1.4×10^{27}

13. What is the cell potential for



$E^\circ = 1.81 \text{ V}$ when $[\text{Sn}^{4+}] = 1.0$, $[\text{Sn}^{2+}] = 1.0 \times 10^{-2}$, and $[\text{Al}^{3+}] = 1.5 \times 10^{-3}$ at 298 K.

- a) 1.70 V d) 1.86 V
b) 1.76 V e) 1.93 V
 c) 1.81 V

$6e^- + 3\text{Sn}^{4+} \rightarrow 3\text{Sn}^{2+}$
 $2\text{Al} \rightarrow 2\text{Al}^{3+} + 6e^-$
 $Q = \frac{[\text{Sn}^{2+}]^3 [\text{Al}^{3+}]^2}{[\text{Sn}^{4+}]^3} = \frac{(2.25 \times 10^{-2})^3 (1.5 \times 10^{-3})^2}{(1.0)^3} = 2.25 \times 10^{-12}$
 $E_{\text{cell}} = 1.81 \text{ V} - \frac{0.0592}{6} \log(2.25 \times 10^{-12}) = 1.92 \text{ V}$
 Nernst Eq.

14. If the potential cell is +1.32 V at $Q = 0.0969$ with $n = 2$, what is the standard potential of the cell? **Nernst Eq.**

- a) +1.35 V d) +1.34 V
b) +1.48 V e) +1.29 V
 c) +1.31 V

$$1.32 \text{ V} = E^\circ - \frac{0.0592}{2} \log(0.0969)$$

$$E^\circ = 1.29 \text{ V}$$

15. Predict the product at the anode when electric current is passed through a solution of KI.

- a) $\text{I}_2(\text{l})$ (s) d) K(s) e^- are lost at (+) electrode
 b) $\text{K}^+(\text{aq})$ e) $\text{O}_2(\text{g})$
 c) $\text{H}_2(\text{g})$

$E^\circ = -1.23 \text{ V}$
 $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4e^-$
 $\text{I}_2 + 2e^- \rightarrow 2\text{I}^-$ ($E^\circ = .535 \text{ V}$) higher E°_{ox}

16. If electric current is passed through aqueous LiBr, the product at the cathode would be

H_2 and the product at the anode would be Br_2 .

- a) $\text{H}_2\text{O}(\text{l})$, $\text{Li}^+(\text{aq})$ d) $\text{Br}_2(\text{l})$, $\text{H}_2(\text{g})$
b) $\text{Br}_2(\text{l})$, $\text{Li}(\text{s})$ e) $\text{H}_2(\text{g})$, $\text{Br}_2(\text{l})$
 c) $\text{Li}(\text{s})$, $\text{Br}_2(\text{l})$

$\text{Br}_2 + 2e^- \rightarrow 2\text{Br}^-$ ($E^\circ = 1.08 \text{ V}$) higher E°_{ox}
 $\text{Li}^+ + e^- \rightarrow \text{Li}$ ($E^\circ = -3.045 \text{ V}$)
 $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4e^-$ ($E^\circ = -1.23 \text{ V}$) higher E°_{red}
 $2\text{H}_2\text{O} + 2e^- \rightarrow \text{H}_2 + 2\text{OH}^-$ ($E^\circ = -.828$)

17. How long would it take to deposit 1.36 g of copper from an aqueous solution of copper(II) sulfate by passing a current of two amperes through the solution? **$\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$**

- a) 2070 sec d) 736 sec
 b) 1.11×10^{-5} sec e) 1030 sec
 c) 2570 sec

$$1.36 \text{ g Cu} \times \frac{1 \text{ mol}}{63.55 \text{ g}} \times \frac{2 \text{ mole } e^-}{1 \text{ mol}} \times \frac{96485 \text{ Coul}}{\text{mole } e^-} \times \frac{1 \text{ s}}{2 \text{ Coul}} = 1030 \text{ sec}$$

18. If a current of 6.0 amps is passed through a solution of Ag^+ for 1.5 hours, how many grams of silver are produced? **$\text{Ag}^+ + e^- \rightarrow \text{Ag}$**

- a) 0.60 g d) 3.0 g
b) 36 g e) 1.0 g
 c) 0.34 g

$$1.5 \text{ hr} \times \frac{3600 \text{ s}}{1 \text{ hr}} \times \frac{6.0 \text{ Coul}}{\text{s}} \times \frac{1 \text{ mole } e^-}{96485 \text{ Coul}} \times \frac{1 \text{ mol Ag}}{1 \text{ mole } e^-} = 36 \text{ g}$$

19. How many kilowatt hours of electrical energy are required to plate 2.00 grams of silver from an aqueous solution of silver nitrate on to a necklace using 3.00V? (1 joule = 1 volt-coulomb and 1 kwh = $3.60 \times 10^6 \text{ J}$)

- a) 0.00135 kwh d) 0.00149 kwh
 b) 0.000165 kwh e) 2.07 kwh
 c) 32.4 kwh

$$2.00 \text{ g Ag} \times \frac{1 \text{ mol}}{107.87 \text{ g}} \times \frac{1 \text{ mole } e^-}{1 \text{ mole}} \times \frac{96485 \text{ Coul}}{1 \text{ mole } e^-} \times \frac{3.00 \text{ V}}{1 \text{ Coul}} = 5367 \text{ J}$$

20. How is aluminum currently produced in industry?

- a) by reduction of Al^{3+} in Al_2O_3 with Na(s)
 b) electrochemical reduction of pure Al_2O_3 to give Al and O_2
 c) electrolysis of AlF_3 to give Al and F_2
d) electrolysis of a mixture of Al_2O_3 and Na_3AlF_6 to give Al and O_2 Hall-Heroult process
 e) by reduction of Al^{3+} in Al_2O_3 with CO(g)

21. How was aluminum originally made?

- a) the Hall-Heroult process
 b) Al_2O_3 mixed with cryolite is electrolyzed
 c) electrolysis of molten Al_2O_3
 d) mining and purifying directly
e) reducing AlCl_3 with sodium very expensive process

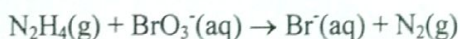
22. Using data from the reduction potential table, predict which of the following is the best oxidizing agent. **most likely Reduced** (top of chart)

- a) F_2 d) Ag^+
 b) Ag e) Al^{3+}
 c) Sn^{4+}

23. Under acidic conditions the bromate ion is reduced to the bromide ion. Write the balanced half-reaction for this process. $\text{BrO}_3^- \rightarrow \text{Br}^-$

- a) $\text{BrO}_3^- + 6\text{H}^+ + 6\text{e}^- \rightarrow \text{Br}^- + 3\text{H}_2\text{O}$
 b) $2\text{BrO}_3^- + 6\text{H}^+ \rightarrow \text{Br}_2 + 6\text{H}_2\text{O} + 3\text{e}^-$
 c) $\text{BrO}_3^- + 6\text{H}_2\text{O} + 10\text{e}^- \rightarrow \text{Br}_2^- + 12\text{H}^+ + 3\text{O}_2$
 d) $2\text{BrO}_3^- + 6\text{H}_2\text{O} \rightarrow 2\text{Br}^- + 12\text{H}^+ + 6\text{O}_2 + 8\text{e}^-$
 e) $2\text{BrO}_3^- + 6\text{H}^+ \rightarrow \text{Br}_2 + 3\text{H}_2\text{O} + 3\text{e}^-$

24. Balance the following redox equation which occurs in acidic solution.



- a) $3\text{N}_2\text{H}_4 + \text{BrO}_3^- \rightarrow 3\text{N}_2 + \text{Br}^- + 3\text{H}_2\text{O} + 6\text{H}^+$
 b) $\text{N}_2\text{H}_4 + \text{BrO}_3^- + 2\text{H}^+ \rightarrow 2\text{Br}^- + \text{N}_2 + 3\text{H}_2\text{O}$
 c) $3\text{N}_2\text{H}_4 + 2\text{BrO}_3^- + 12\text{H}^+ \rightarrow 3\text{N}_2 + 2\text{Br}^- + 6\text{H}_2\text{O} + 12\text{H}^+$
 d) $\text{N}_2\text{H}_4 + 2\text{BrO}_3^- + 8\text{H}^+ \rightarrow 2\text{Br}^- + \text{N}_2 + 6\text{H}_2\text{O}$
 e) $3\text{N}_2\text{H}_4 + 2\text{BrO}_3^- \rightarrow 3\text{N}_2 + 2\text{Br}^- + 6\text{H}_2\text{O}$

25. Which of the following reactions is NOT a redox reaction?

- a) $2\text{HgO}(\text{s}) \rightarrow 2\text{Hg}(\text{l}) + \text{O}_2(\text{g})$
 b) $\text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightarrow 2\text{HBr}(\text{g})$
 c) $2\text{HCl}(\text{aq}) + \text{Zn}(\text{s}) \rightarrow \text{H}_2(\text{g}) + \text{ZnCl}_2(\text{aq})$
 d) $\text{H}_2\text{CO}_3(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ no change in oxidation #'s
 e) $2\text{KClO}_3 \rightarrow 2\text{KCl}(\text{s}) + 3\text{O}_2(\text{g})$

$$\#11) \Delta G = -nFE = (-2 \text{ mol e}^-)(96485 \text{ C/mol e}^-)(1.265 \text{ V}) = -51137 \text{ C}\cdot\text{V} = -51137 \text{ J}$$

$$\Delta G = -RT \ln K = -51137 \text{ J}$$

$$\ln K = \frac{-51137 \text{ J}}{-(8.314 \text{ J/K}\cdot\text{mol})(298 \text{ K})} = 20.64$$

$$K = e^{20.64} = 9.2 \times 10^8 \quad (\text{B})$$

$$\#12) -nFE = -RT \ln K \quad \Delta G$$

$$\ln K = \frac{nFE}{RT} = \frac{2(96485)(1.78)}{(8.314)(293 \text{ K})} = 61.788$$

$$K = e^{61.788} = 6.83 \times 10^{26} \quad (\text{B})$$

Standard Reduction Potentials at 25°C E° (volts)

$\text{F}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{F}^-(\text{aq})$	+2.87
$\text{Au}^{3+} + 3\text{e}^- \rightarrow \text{Au}(\text{s})$	+1.50
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{Cl}^-(\text{aq})$	+1.36
$\text{O}_2(\text{g}) + 4\text{H}_3\text{O}^+(\text{aq}) + 4\text{e}^- \rightarrow 6\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightarrow 2\text{Br}^-(\text{aq})$	+1.08
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$	+0.80
$\text{I}_2(\text{s}) + 2\text{e}^- \rightarrow 2\text{I}^-(\text{aq})$	+0.535
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})$	+0.337
$\text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Sn}^{2+}(\text{aq})$	+0.15
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Sn}(\text{s})$	-0.14
$\text{Cd}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cd}(\text{s})$	-0.40
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Zn}(\text{s})$	-0.763
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$	-0.828
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightarrow \text{Al}(\text{s})$	-1.66
$\text{K}^+(\text{aq}) + \text{e}^- \rightarrow \text{K}(\text{s})$	-2.93
$\text{Li}^+(\text{aq}) + \text{e}^- \rightarrow \text{Li}(\text{s})$	-3.045

Answers:

1. C	11. B	21. E
2. A	12. B	22. A
3. A	13. E	23. A
4. A	14. E	24. E
5. E	15. A	25. D
6. B	16. E	
7. C	17. A	
8. E	18. B	
9. D	19. D	
10. E	20. D	

