Name:
AP Chemistry
Date:
Period:

Empower Yourself
Empower Your Community
Empower Your World

Triathlon – Electrochemistry

Balancing Redox Reactions

1. Balance the following in acidic solution:

$$P + Cu^{2+} \rightarrow Cu + H_2PO_4^-$$

$[3e^- + 2H^+ + P \rightarrow H_2PO_4^-]\,2$ $\quad [2e^- + Cu^{2+} \rightarrow Cu]\,3$

$4H^+ + 2P + 3Cu^{2+} \rightarrow 3Cu + 2H_2PO_4^-$

2. Balance the following in acidic solution:

$$NO_2 \rightarrow NO_3^- + NO$$

$[H_2O + NO_2 \rightarrow NO_3^- + 2H^+ + 1e^-]\,2$ $\quad 2e^- + 2H^+ + NO_2 \rightarrow NO + H_2O$

$H_2O + NO_2 + NO_2 \rightarrow 2NO_3^- + 2H^+ + NO$

3. Balance the following in basic solution:

$$MnO_4^- + C_2O_4^{2-} \rightarrow MnO_2 + CO_2$$

$[3e^- + 4H^+ + MnO_4^- \rightarrow MnO_2 + 2H_2O]\,2$ $\quad [C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-]\,3$

$8OH^- \; 8H^+ + 2MnO_4^- + 3C_2O_4^{2-} \rightarrow 6CO_2 + 2MnO_2 + 2H_2O + 8OH^-$

$6H_2O + 2MnO_4^- + 3C_2O_4^{2-} \rightarrow 6CO_2 + 2MnO_2 + 8OH^-$

4. Balance the following in basic solution:

$$Cu(NH_3)_4^{2+} + S_2O_4^{2-} \rightarrow SO_3^{2-} + Cu + NH_3$$

$2e^- + Cu(NH_3)_4^{2+} \rightarrow Cu + 4NH_3$ $\quad 2H_2O + S_2O_4^{2-} \rightarrow 2SO_3^{2-} + 4H^+ + 4e^-$

$2Cu(NH_3)_4^{2+} + 2H_2O + S_2O_4^{2-} \rightarrow Cu + 4NH_3 + 2SO_3^{2-} + 4H^+$

$4OH^- + 2Cu(NH_3)_4^{2+} + S_2O_4^{2-} \rightarrow Cu + 4NH_3 + 2SO_3^{2-} + 2H_2O$

Voltaic Cells and E°

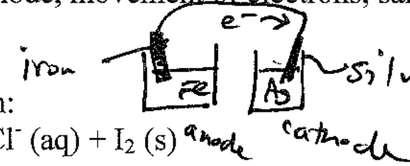
5. 1. You create a voltaic cell with the following reaction:

$$Fe\,(s) + 2\,Ag^+\,(aq) \rightarrow Fe^{2+}\,(aq) + 2\,Ag\,(s)$$

Name:
AP Chemistry
Date:
Period:

Empower Yourself
Empower Your Community
Empower Your World

Create a diagram of the two half cells. Label the cathode, anode, movement of electrons, salt bridge, and write in cell notation.



6. Calculate the standard reduction potential for the reaction:

$$Cl_2 + 2\,I^- (aq) \rightarrow 2\,Cl^- (aq) + I_2 (s)$$

$\mathcal{E}^\circ = \mathcal{E}^\circ_{cathode} - \mathcal{E}^\circ_{anode} = 1.36 - 0.54 = \boxed{0.82\ V}$

7. Calculate the standard reduction potential for the reaction:

$$Ni (s) + 2\,Ce^{4+} (aq) \rightarrow Ni^{2+} (aq) + 2\,Ce^{3+}$$

$\mathcal{E}^\circ = 1.63 - {}^{-}0.28 = \boxed{1.96\ V}$

8. Which of the following is a stronger oxidizing agent: Fe (s) or Mg (s)

Fe is a stronger oxidizing agent

Nernst Equation

9. Find the emf for the following cell reaction at 298 K:

$$Zn(s) + Ni^{2+} (aq) \rightarrow Zn^{2+} (aq) + Ni(s)$$
$$[Ni^{2+}] = 3.00\ M,\ [Zn^{2+}] = 0.100\ M$$

$\mathcal{E} = \mathcal{E}^\circ - \frac{0.0257}{2} \ln\left(\frac{0.1}{3}\right)$

$\mathcal{E} = 0.48 - 0.01285 \ln\left(\frac{0.1}{3}\right) = 0.48 - {}^{-}0.0437 = \boxed{0.52\ V}$

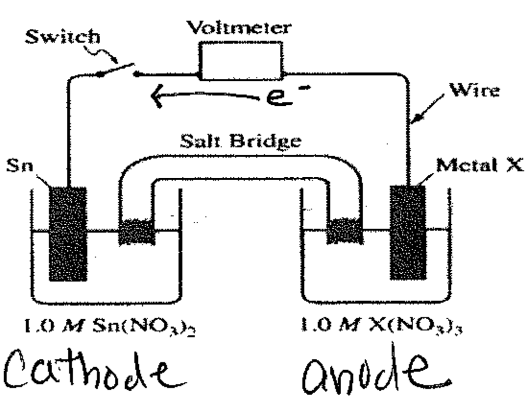
10. Find the emf for the following cell reaction at 298 K:

$$Zn(s)\ |\ Zn^{2+}\ (0.5\ M)\ ||\ Cu^{2+}\ (0.891\ M)\ |\ Ag(s) \Rightarrow \mathcal{E}^\circ = 1.1V$$

$\mathcal{E} = 1.1 - \frac{0.0257}{2} \ln\left(\frac{0.5}{0.891}\right)$

$\mathcal{E} = 1.1 - {}^{-}0.0074 = \boxed{1.11\ V}$

11.



Name:
AP Chemistry
Date:
Period:

Empower Yourself
Empower Your Community
Empower Your World

An electrochemical cell is constructed with an open switch, as shown in the diagram above. A strip of Sn and a strip of unknown metal, X are used as electrodes. When the switch is closed, the mass of the Sn electrode increases. The half-reactions are shown below.

$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$ $\quad E^\circ = -0.14$ V

$X^{3+}(aq) + 3e^- \rightarrow X(s)$ $\quad E^\circ = ?$

(a) In the diagram above, label the electrode that is the cathode. Justify your answer.

(b) In the diagram above, draw an arrow indicating the direction of electron flow in the external circuit when the switch is closed.

(c) If the standard cell potential E°_{cell} is +0.60 V, what is the standard potential, in volts for the X^{3+}/X electrode?

$0.60 = -0.14 - E^\circ_M$

$-0.74\text{ V} = E^\circ_M$

(d) Identify metal X.

$Cr^{3+} + 3e^- \rightarrow Cr(s)$

(e) Write balanced net-ionic equation for the overall chemical reaction occurring in the cell.

$3Sn(s) + 2Cr^{3+} \rightarrow 2Cr + 3Sn^{2+}$

(f) In the cell, the concentration of Sn^{2+} is changed from 1.0 *M* to 0.50 *M*, and the concentration of X^{3+} is changed from 1.0 *M* to 0.10 *M*.

(i) Substitute all appropriate values for determining the cell potential, E_{cell}, into the Nernst equation. (Do not do any calculations.)

$$E = 0.60 - \frac{0.0257}{6} \ln\left(\frac{(0.50)^3}{(0.1)^2}\right)$$

(ii) On the basis of your response in (f) (i), will the cell potential be greater than, less than, or equal to E°_{cell}? Justify your answer.

The cell potential with be ~~greater~~ less than E°_{cell}. This is due to the fact ln(Q) would be greater than 1, so lnQ is positive and the overall term is negative.

Name:
AP Chemistry
Date:
Period:

Empower Yourself
Empower Your Community
Empower Your World

Zn^{2+} (conc) → Zn^{2+} (dilute)

Concentration Cells

12. A voltaic cell is constructed with 2 Zn^{2+} - Zn electrodes. The two half cells have $[Zn^{2+}]$ = 1.8 M and $[Zn^{2+}]$ = 1.00 x 10^{-2} M, respectively

a. Which electrode is the anode of the cell?

$[Zn^{2+}] = 1 \times 10^{-2}$ M

b. What is the standard emf of the cell?

$\mathcal{E}^\circ = 0$ V

c. What is the cell emf for the concentrations given?

$\mathcal{E} = 0 - \frac{0.0257}{2} \ln\left(\frac{1 \times 10^{-2}}{1.8}\right) = \boxed{0.067 \text{ V}}$

d. For each electrode, predict whether $[Zn^{2+}]$ will increase, decrease, or remain the same as the cell operates.

Cathode ⇒ $[Zn^{2+}]$ ↓ w/ time
anode ⇒ $[Zn^{2+}]$ ↑ w/ time

13. A voltaic cell is constructed with two silver-silver chloride electrodes, each of which is based on the following half-reactions:

$$AgCl\ (s) + e^- \rightarrow Ag\ (s) + Cl^-\ (aq)$$

The two half cells have $[Cl^-]$ = 0.0150 M and $[Cl^-]$ = 2.55, respectively.

a. Which electrode is the cathode of the cell?

$[Cl^-] = 2.55$ M

b. What is the standard emf of the cell?

$\mathcal{E}^\circ = 0$ V

c. What is the cell emf for the concentrations given?

$\mathcal{E} = 0 \text{ V} - \frac{0.0257}{1} \ln\left(\frac{0.015}{2.55}\right) = \boxed{0.132 \text{ V}}$

d. For each electrode, predict whether $[Cl^-]$ will increase, decrease, or remain the same.

cathode ⇒ $[Cl^-]$ ↓ w/ time
anode ⇒ $[Cl^-]$ ↑ w/ time

ΔG, K_{eq}, and E°

14. The following galvanic electrochemical cell was constructed:

Pt (s) | H_2 (g, 1.00 atm) | H^+ (aq, concentration unknown) || Ag^+ (aq, 0.10 M) | Ag (s)

a. Write the balanced chemical equation **and** calculate E°_{cell} for this galvanic electrochemical cell. Recall that E° = 0.800 V for $Ag^+ + e^- \rightarrow Ag$ (s) and H_2/H^+ = 0.00 V

$H_2 \rightarrow 2H^+ + 2e^-$ $\qquad$ $Ag^+ + 1e^- \rightarrow Ag$

$\boxed{H_2 + 2Ag^+ \rightarrow 2H^+ + 2Ag}$ $\qquad$ $\boxed{\mathcal{E}^\circ = 0.800 \text{ V}}$

Name:
AP Chemistry
Date:
Period:

Empower Yourself
Empower Your Community
Empower Your World

b. The source of protons in the hydrogen half – cell is a buffer composed of 0.10 M C_6H_5COOH and 0.050 M $C_6H_5COO^-$. The measured cell potential is 0.971 V. Given this fact, determine the pH of the solution **and** the value of K_a for benzoic acid (C_6H_5COOH).

(on back)

15. A galvanic cell is based constructed based on the following half-reactions:

$$Ag^+ (aq) + e^- \rightarrow Ag (s) \quad E^o = 0.799 \text{ V}$$
$$Cu^{2+} (aq) + 2e^- \rightarrow Cu (s) \quad E^o = 0.345 \text{ V}$$

In this cell, the Ag^+/Ag half cell contains a silver electrode and a saturated solution of AgCl ($K_{sp} = 1.6 \times 10^{-10}$), The Cu/Cu^{2+} half cell contains 1.0 L of a 2.0 M solution of $Cu(NO_3)_2$ and a copper electrode.

a. Calculate the cell potential for this electrochemical cell

$$\mathcal{E} = 0.454 - \frac{0.0257}{2} \ln\left(\frac{(2)}{[Ag]^2}\right)$$ Find w/ Ksp

$AgCl \rightleftharpoons Ag^+ + Cl^-$

$K_{sp} \sqrt{1.6 \times 10^{-10}} = \sqrt{x^2}$

$1.26 \times 10^{-5} M = x$

$$\mathcal{E} = 0.454 - 0.01285 \ln\left(\frac{2}{(1.26 \times 10^{-5})^2}\right)$$

$$\mathcal{E} = 0.454 - 0.299 = \boxed{0.155 \text{ V}}$$

~~b. Calculate the moles of NH_3 (assume no volume change) that would need to be added to the Cu/Cu^{2+} half cell to give a cell potential of 0.52 V. To answer this question, consider the following reaction:~~

~~$$Cu^{2+} (aq) + 4NH_3 (aq) \rightarrow Cu(NH_3)_4^{2+} (aq) \quad K_f = 1.0 \times 10^{13}$$~~