Electrochemistry Problems

1. When a solution containing iodide ion is mixed with manganese dioxide and acid, a cloud of purple iodine gas is given off. Use a table of half reactions to

   a) write the half reactions that occur.

   $2I^- \rightarrow I_2 + 2e^-$

   $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

   b) write the balanced redox reaction.

   $2I^- + MnO_2 + 4H^+ \rightarrow I_2 + Mn^{2+} + 2H_2O$

2. When hot cesium metal is exposed to chlorine gas, a bright flash occurs as the elements react. The product is a white solid composed of cesium ions and chloride ions.

   a) Write the half reactions that occur.

   $Cs \rightarrow Cs^+ + e^-$

   $Cl_2 + 2e^- \rightarrow 2Cl^-$

   b) Write the balanced redox reaction.

   $2Cs + Cl_2 \rightarrow 2Cs^+ + 2Cl^-$

   $2Cs + Cl_2 \rightarrow 2CsCl$

3. A cell is made up as follows. A piece of nickel foil is immersed in a beaker of nickel(II) chloride solution, and a strip of copper foil is immersed in a beaker of copper(II) sulfate solution. A wire then connects the metal electrodes and the beakers connected by a salt bridge.

   a) Write the half reactions that occur. Identify the oxidation half and the reduction half.

   $Ni^{2+} + 2e^- \rightarrow Ni \quad -0.26$
   $Cu^{2+} + 2e^- \rightarrow Cu \quad +0.34$
   $\Rightarrow$ ox ½ $Ni \rightarrow Ni^{2+} + 2e^-$
   red ½ $Cu^{2+} + 2e^- \rightarrow Cu$

   b) Which electrode is the anode?

   Nickel

   c) Toward which electrode do the sulfate ions migrate?

   towards nickel (anode)

   d) Which way do the electrons migrate in the wire?

   from nickel (anode) to copper (cathode)

   e) If 0.025 mol of copper is produced in the reaction, how many moles of electrons flow through the wire?

   $Cu^{2+} + 2e^- \rightarrow Cu \quad \therefore \quad (0.025\,mol\,Cu)\left(\frac{2\,mol\,e^-}{1\,mol\,Cu}\right) = 0.050\,mol\,e^-$

   f) Toward which electrode do the nickel ions migrate? towards Cu (cathode)

4. An electrochemical cell was made as follows. A weighed strip of tin was immersed in a beaker of one molar tin(II) sulfate and a weighed strip of silver was immersed in a second beaker containing one molar silver nitrate. A wire then connected the metal strips and a salt bridge connected the beakers.

a) What is the balanced redox equation for the reaction?

$Sn^{2+} + 2e^- \rightarrow Sn \quad -0.14$
$Ag^+ + e^- \rightarrow Ag \quad +0.80$ $\Rightarrow$ ox $Sn \rightarrow Sn^{2+} + 2e^-$, red $Ag^+ + e^- \rightarrow Ag$

$$2Ag^+ + Sn \rightarrow Sn^{2+} + 2Ag$$

b) Which electrode is the cathode?

Ag

c) Towards which electrode do the silver ions migrate?

towards Ag (cathode)

d) Which way do the electrons flow in the wire?

from Sn to Ag (anode to cathode)

e) Did the silver electrode gain or lose mass?

gains mass ($Ag^+ + e^- \rightarrow Ag$) silver ions change to silver + deposit on the cathode

f) If 0.010 mol of tin goes into solution, how many moles of electrons flow through the wire?

$Sn^{2+} + 2e^- \rightarrow Sn$ $\quad (0.010 \text{ mol Sn})\left(\frac{2 \text{ mol } e^-}{1 \text{ mol Sn}}\right) = 0.020 \text{ mol } e^-$

g) If 0.020 mol of tin goes into solution, how many moles of silver are involved in the reaction?

$(0.020 \text{ mol Sn})\left(\frac{2 \text{ mol Ag}}{1 \text{ mol Sn}}\right) = 0.040 \text{ mol Ag}$

h) How many moles of electrons flow through the salt bridge in part (g)?

none - electrons flow through the wire not the salt bridge.

5. Calculate the potential for the following cells and indicate whether the reaction is expected to be spontaneous.

a) $Cr + 3Ag^+ \rightarrow Cr^{3+} + 3Ag$

$Cr \rightarrow Cr^{3+} + 3e^- \quad +0.74 \text{ V}$
$Ag^+ + e^- \rightarrow Ag \quad +0.80 \text{ V}$
$+1.54 \text{ V}$ = spontaneous

b) $Cu^+ + Fe^{3+} \rightarrow Cu^{2+} + Fe^{2+}$

$Cu^+ \rightarrow Cu^{2+} + 1e^- \quad -0.16 \text{ V}$
$Fe^{3+} + e^- \rightarrow Fe^{2+} \quad +0.77 \text{ V}$
$+0.61 \text{ V}$ = spontaneous

c) $Mn^{2+} + 2H_2O + I_2 \rightarrow MnO_2 + 4H^+ + 2I^-$

$Mn^{2+} + 2H_2O \rightarrow MnO_2 + 4H^+ + 2e^- \quad -1.23 \text{ V}$
$I_2 + 2e^- \rightarrow 2I^- \quad +0.54 \text{ V}$
-0.69 V = non-spontaneous

d) $2Cr^{3+} + 7H_2O + 3Pb^{2+} \rightarrow Cr_2O_7^{2-} + 14H^+ + 3Pb$

$2Cr^{3+} + 7H_2O \rightarrow Cr_2O_7^{2-} + 14H^+ + 6e^- \quad -1.33 \text{ V}$
$Pb^{2+} + 2e^- \rightarrow Pb \quad -0.13 \text{ V}$
-1.46 V = nonspontaneous

6. Which is the stronger oxidizing agent?

a) Zn^{2+} or Ca^{2+} Zn^{2+}

-0.76 -2.84

b) Br_2 or I_2 Br_2

1.06 0.54

7. Which is the stronger reducing agent?

a) Mn or Pb Mn

1.18 0.13

b) Ba or Sn Ba

2.92 0.14

8. Which of Cr, I_2, Al and Fe^{3+} will oxidize Co?

Cr, Al can't reduce, ∴ cannot oxidize Co $Co \rightarrow Co^{2+} + 2e^- \quad +0.28$

I_2 or Fe^{3+} $I_2 + 2e^- \rightarrow 2I^- \quad +0.54$ $Fe^{3+} + e^- \rightarrow Fe^{2+} \quad +0.77$

9. Which of H_2, Cl_2, Hg^{2+}, and H_2O_2 will reduce Ag^+?

$Ag^+ + e \rightarrow Ag \quad +0.80$ $H_2 \rightarrow 2H^+ + 2e^- \quad 0\ V$ Hg^{2+} ✗

H_2 or H_2O_2 Cl_2 ✗ $H_2O_2 \rightarrow O_2 + 2H^+ + 2e^- \quad -0.70\ V$

10. Which of Cu^{2+}, Zn, acidic NO_3^-, and Cl^- will act as oxidizing agents for Ag?

$Cu^{2+} + 2e^- \rightarrow Cu \quad +0.34$ $NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O \quad 0.96\ V$ $Ag \rightarrow Ag^+ + e^- \quad -0.80$

Zn ✗ Cl^- ✗ only NO_3^-

11. Which of I^-, Pb, Br_2, and Sn^{2+} will act as ~~oxidizing~~ reducing agents for Sn^{4+}?

$2I^- \rightarrow I_2 + 2e^- \quad -0.54$ Br_2 ✗ $Sn^{4+} + 2e^- \rightarrow Sn^{2+} \quad +0.15$

$Pb \rightarrow Pb^{2+} + 2e^- \quad +0.13V$ $Sn^{2+} \rightarrow Sn^{4+} + 2e^- \quad -0.15\ V$ ∴ only Pb

12. Predict the reaction that will be favoured in the following cells.

a) A mixture of Br_2 and Cl_2 is added to a beaker containing copper(II) sulfate and a copper rod.

Br_2, Cl_2, Cu^{2+}, SO_4^{2-}, Cu, H_2O

ox

$Cu \rightarrow Cu^{2+} + 2e^- \quad -0.34\ V$

$Cu \rightarrow Cu^+ + e^- \quad -0.52\ V$

$H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad -0.82$

red

~~50~~

$Cl_2 + 2e^- \rightarrow 2Cl^- \quad 1.36\ V$

$Br_2 + 2e^- \rightarrow 2Br^- \quad 1.06\ V$

$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad -0.41\ V$

$Cu^{2+} + e^- \rightarrow Cu^+ \quad +0.16\ V$

$Cu^{2+} + 2e^- \rightarrow Cu \quad +0.34\ V$

$$Cl_2 + Cu \rightarrow Cu^{2+} + 2\ Cl^-$$

b) A mixture of powdered Al and Fe is added to a beaker of Cr^{3+} solution.

Al, Fe, Cr^{3+}, H_2O

ox

$Al \rightarrow Al^{3+} + 3e^- \quad +1.68$

$Fe \rightarrow Fe^{3+} + 3e^- \quad +0.04$

$Fe \rightarrow Fe^{2+} + 2e^- \quad +0.44$

$2Cr^{3+} + 7H_2O \rightarrow Cr_2O_7^{2-} + 14H^+ + 6e^- \quad -1.33\ V$

$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad -0.82\ V$

red

$Cr^{3+} + e^- \rightarrow Cr^{2+} \quad -0.42\ V$

$Cr^{3+} + 3e^- \rightarrow Cr \quad -0.74\ V$

$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad -0.41\ V$

$$2\ Al + 6\ H_2O \rightarrow 2\ Al^{3+} + 3\ H_2 + 6\ OH^-$$

c) A tin strip is immersed in nitric acid. Sn, H^+, NO_3^-, H_2O

ox
$Sn \rightarrow Sn^{2+} + 2e^-$ $+0.14\ V$
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ -0.82

red
$2H^+ + 2e^- \rightarrow H_2$ 0.00
$NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$ $+0.96$
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ $-0.41\ V$

$$3\,Sn + 2\,NO_3^- + 8H^+ \rightarrow 3\,Sn^{2+} + 2\,NO + 4\,H_2O$$

d) A copper rod is immersed in a 1 M solution of HCl, through which is bubbled O_2 at 101.3 kPa.

Cu, H^+, Cl^-, O_2, H_2O

ox
$Cu \rightarrow Cu^{2+} + 2e^-$ -0.34
$Cu \rightarrow Cu^+ + e^-$ -0.52
$2Cl^- \rightarrow Cl_2 + 2e^-$ $-1.36\ V$
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ $-0.82\ V$

red
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ 1.23
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ -0.41
$2H^+ + 2e^- \rightarrow H_2$ 0.00
$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$ $+0.70$

$$2Cu + O_2 + 4H^+ \rightarrow 2Cu^{2+} + 2H_2O$$

13. Predict the overall reactions that you would expect when the following are electrolyzed. Calculate the minimum voltage that must be applied to the cell.

a) 1 M NaI Na^+, I^-, H_2O

ox
$2I^- \leftrightarrow I_2 + 2e^-$ -0.54
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ -0.82

red
$Na^+ + e^- \rightarrow Na$ -2.71
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ -0.41

$$2I^- + 2H_2O \rightarrow I_2 + H_2 + 2OH^-$$

0.95 V must be applied

b) 1M KCl K^+, Cl^-, H_2O

ox
$2Cl^- \leftrightarrow Cl_2 + 2e^-$ -1.36
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ -0.82

red
$K^+ + e^- \rightarrow K$ -2.93
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ -0.41

$$2H_2O + 4H_2O \rightarrow O_2 + 4H^+ + 2H_2 + 4OH^-$$
$$6H_2O \rightarrow O_2 + 4H^+ + 2H_2 + 4OH^-$$

1.23 V must be applied

c) 1 M CuF_2 Cu^{2+}, F^-, H_2O

ox $2F^- \rightarrow F_2 + 2e^-$ −2.87

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ −0.82

red $Cu^{2+} + 2e^- \rightarrow Cu$ +0.34

$Cu^{2+} + e^- \rightarrow Cu^+$ +0.16

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ −0.41

$2H_2O + 2Cu^{2+} \rightarrow O_2 + 4H^+ + 2Cu$ 0.48 V must be applied

d) 1 M CoI_2 and 1 M HCl Co^{2+}, I^-, H^+, Cl^-, H_2O

ox $2I^- \rightarrow I_2 + 2e^-$ −0.54

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ −0.82

$2Cl^- \rightarrow Cl_2 + 2e^-$ −1.36 V

red $Co^{2+} + 2e^- \rightarrow Co$ −0.28

$2H^+ + 2e^- \rightarrow H_2$ 0.00

~~$2Cl^- \rightarrow Cl_2 + 2e^-$ −1.36~~

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ −0.41

$2I^- + 2H^+ \rightarrow I_2 + H_2$ 0.54 V must be applied

e) 1 M NaOH, using Fe electrodes Na^+, OH^-, Fe, H_2O

ox $Fe \rightarrow Fe^{2+} + 2e^-$ +0.44

$Fe \rightarrow Fe^{3+} + 3e^-$ +0.04

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ −0.82

$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ −0.40

red $Na^+ + e^- \rightarrow Na$ −2.71

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ −0.41

$Fe + 2H_2O \rightarrow Fe^{2+} + H_2 + 2OH^-$ spontaneous +0.03V no voltage required

f) 1 M HI, using Cu electrodes H^+, I^-, Cu, H_2O

ox $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ −0.82

$2I^- \rightarrow I_2 + 2e^-$ −0.54

$Cu \rightarrow Cu^+ + e^-$ −0.52

$Cu \rightarrow Cu^{2+} + 2e^-$ −0.34

red $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ −0.41

$2H^+ + 2e^- \rightarrow H_2$ 0.00

$Cu + 2H^+ \rightarrow Cu^{2+} + H_2$ 0.34 V must be applied

14. An aqueous solution of sodium sulfate is electrolyzed. If litmus paper is dipped in the solution around the anode during electrolysis, what colour will the litmus turn? What colour will the litmus turn when dipped in the solution around the cathode? If the electric current is turned off and the anode and cathode solutions are stirred together, what will be the pH of the resulting solution?

Na^+ , SO_4^{2-} , H_2O

ox

$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad -0.82\ V$

↑ anode rx

red

$Na^+ + e^- \rightarrow Na \quad -2.71\ V$

$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad -0.41\ V$

↑ cathode rx

anode → H^+ produced

litmus turns red

cathode → OH^- produced

litmus turns blue

mixed ⇒ $2H_2O + 4H_2O \rightarrow O_2 + 4H^+ + 2H_2 + 4OH^-$

$6H_2O \rightarrow O_2 + 4H^+ + 2H_2 + 4OH^-$

$(2H_2O \rightarrow O_2 + 2H_2) \rightarrow$ pH = 7 $\quad OH^- = H^+$

15. How many moles of Cu can be produced by passing a 2.50 A current through 1 M $CuSO_4$ for 4000. s?

coulombs = (2.50 A)(4000. s) = 10 000 C

$\frac{10\,000\ C}{96\,500\ C/mol\ e^-} = 0.104\ mol\ e^-$ $\quad Cu^{2+} + 2e^- \rightarrow Cu$

$(0.104\ mol\ e^-)\left(\frac{1\ mol\ Cu}{2\ mol\ e^-}\right)\left(\frac{63.546\ g}{mol}\right) = 3.29\ g\ Cu$

$0.0052\ mol\ Cu$

16. How many coulombs are required to produce 0.325 g of I_2 by electrolysis of an aqueous solution of KI?

$2I^- \rightarrow I_2 + 2e^-$

$\left(\frac{0.325\ g\ I_2}{253.809\ g/mol}\right)\left(\frac{2\ mol\ e^-}{1\ mol\ I_2}\right) = 0.002\,56\ mol\ e^-$

$(0.002\,56\ mol\ e^-)(96\,500\ C/mol\ e^-) = 247\ C$

17. A 12.5 A current was passed through a 1.00 M solution of lead(II) nitrate for 1.00 h using inert electrodes. How much will the mass of the cathode have increased after 1.00 h?

coulombs = (12.5 A)(3600 s) = 45 000 C

$\frac{45\,000\ C}{96\,500\ C/mol\ e^-} = 0.466\ mol\ e^-$ $\quad Pb^{2+} + 2e^- \rightarrow Pb$

$(0.466\ mol\ e^-)\left(\frac{1\ mol\ Pb}{2\ mol\ e^-}\right)(207.2\ g/mol) = \underline{48.3\ g}$

18. What quantity of electricity (in coulombs) is required to produce 1.00 kg of Br_2 by electrolysis of KBr solution?

$2\ Br^- \rightarrow Br_2 + 2e^-$

$\left(\frac{1000\ g\ Br_2}{159.808\ g/mol}\right)\left(\frac{2\ mol\ e^-}{1\ mol\ Br_2}\right)(96\,500\ C/mol\ e^-) = \underline{1.21 \times 10^6\ C}$

19. What mass of tin can be plated out of a Sn^{2+} solution if we pass 3.00 A for 6.00 h?

coulombs = (3.00 A)(21 600 s) = 64 800 C $\quad Sn^{2+} + 2e^- \rightarrow Sn$

$\left(\frac{64\,800\ C}{96\,500\ C/mol\ e^-}\right)\left(\frac{1\ mol\ Sn}{2\ mol\ e^-}\right)(118.69\ g/mol) = \underline{39.9\ g\ Sn}$

20. A certain amount of electricity deposits 45.0 g of silver from a solution containing silver ions. What mass of copper will this amount of electricity deposit from a solution of copper(II) sulfate?

$Ag^+ + e^- \rightarrow Ag$ $\qquad Cu^{2+} + 2e^- \rightarrow Cu$

$\left(\frac{45.0\ g\ Ag}{107.868\ g/mol}\right)\left(\frac{1\ mol\ e^-}{1\ mol\ Ag}\right) = 0.417\ mol\ e^-$

$(0.417\ mol\ e^-)\left(\frac{1\ mol\ Cu}{2\ mol\ e^-}\right)(63.546\ g/mol) = \underline{13.3\ g\ Cu}$