**1.** **(5 points each)** A galvanic cell is constructed that carries out the reaction

$$Pb^{2+}(aq) + 2\,Cr^{2+}(aq) \rightarrow Pb(s) + 2\,Cr^{3+}(aq)$$

The initial concentration of $Pb^{2+}(aq)$ is 0.15 M, that of $Cr^{2+}(aq)$ is 0.20 M, and that of $Cr^{3+}(aq)$ is 0.0030 M, and T = 25°C.

(a) Calculate the standard cell potential.

$Pb^{2+} + 2e^- \rightarrow Pb \quad -0.1263\,V$

$Cr^{2+} \rightarrow e^- + Cr^{3+} \quad +0.424\,V$

$\Delta\mathcal{E}° = 0.298\,V$

(b) Calculate the initial cell voltage.

$$\Delta\mathcal{E} = \Delta\mathcal{E}° - \frac{RT}{nF}\ln Q = \Delta\mathcal{E}° - \frac{0.05916\,V}{n}\log Q$$

$$Q = \frac{(0.0030)^2}{(0.15)(0.20)^2} = 0.0015$$

$$\Delta\mathcal{E} = 0.298\,V - (-0.0835\,V) = 0.382\,V$$

(c) What is the maximum work this cell can do?

$$w_{rev} = -nF\Delta\mathcal{E} = -2(96485\ C/mol\ e^-)(0.382\,V) = -73.6\ kJ/mol$$

(d) Which electrode is the <u>cathode</u> and what is its sign?.

Lead (+)

(e) Calculate the equilibrium constant for the overall cell reaction.

$$\Delta\mathcal{E} = \Delta\mathcal{E}° - \frac{0.05916\,V}{n}\log Q$$

$$0 = \Delta\mathcal{E}° - \frac{0.05916\,V}{n}\log K$$

$$K = 10^{\left(\frac{n\Delta\mathcal{E}°}{0.05916\,V}\right)}$$

$$K = 1.19 \times 10^{10}$$

**2.** **(15 points)** Consider the fuel cell that accomplishes the overall reaction

$$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(\ell)$$

If the fuel cell operates with 60% efficiency, calculate the amount of electrical work generated per gram of water produced. The gas pressures are constant at 1 atm, and the temperature is 25°C.

$H_2 + 2H_2O \rightarrow 2e^- + 2H_3O^+$ 0.000 V

$O_2 + 4H_3O^+ + 4e^- \rightarrow 6H_2O$ 1.229 V

$w = \varepsilon \cdot w_{rev} = \varepsilon(-nF\Delta\mathcal{E})$

$w = -(.6)(2)(96485\ C/mol\ e^-)(1.229\ V)$

$w = -142\ kJ/mol\left(\frac{mol}{18.02\ g}\right)$

$w = -7.88\ kJ/g$

**3.** **(15 points)** A 0.100 M neutral aqueous $CaCl_2$ solution is electrolyzed using platinum electrodes. A current of 1.50 A passes through the solution for 50.0 hours.

(a) Write the half-reactions occurring at the anode and at the cathode.

Anode: $2Cl^- \rightarrow 2e^- + Cl_2$
Cathode: $Ca^{2+} + 2e^- \rightarrow Ca$
4.19 V is greater than decomp. potential of water

Anode: $6H_2O \rightarrow O_2 + 4H_3O^+ + 4e^-$
Cathode: $2H_3O^+ + 2e^- \rightarrow H_2 + 2H_2O$

(b) What is the decomposition potential?

$\Delta\mathcal{E}^\circ = 1.229\ V$

(c) Calculate the mass, in grams, of the product formed at the cathode.

$Q = nF$

$n = \frac{It}{F} = \frac{(1.50\ A)(50.0\ hr)(3600\ s/hr)}{96485\ C/mol\ e^-} = 2.80\ mol\ e^-$

$m = 2.80\ mol\ e^-\left(\frac{1\ mol\ H_2}{2\ mol\ e^-}\right)\left(\frac{2.016\ g\ H_2}{mol}\right) = 2.82\ g\ H_2$

**4.** **(5 points each)** Strontium-90 is one of the most hazardous products of atomic weapons testing because of its long half-life ($t_{1/2}$ = 28.1 years) and its tendency to accumulate in bone.

(a) Write nuclear equations for the decay of $^{90}$Sr via the successive emission of two beta particles.

$$^{90}_{38}Sr \rightarrow {}^{0}_{-1}e^- + {}^{90}_{39}Y \rightarrow {}^{0}_{-1}e^- + {}^{90}_{40}Zr$$

$$^{90}Sr \rightarrow {}^{90}Zr + 2\,{}^{0}_{-1}e^-$$

(b) The atomic mass of $^{90}$Sr is 89.9073 u and that of $^{90}$Zr is 89.9043 u. Calculate the energy released per $^{90}$Sr atom, in MeV, in decaying to $^{90}$Zr.

$$\Delta m = {}^{90}Zr - {}^{90}Sr = -0.00300u$$

$$\Delta E = (-0.00300u)\left(\frac{931.49\ MeV}{u}\right) = -2.79\ MeV$$

$$\Delta m = -4.98 \times 10^{-30}\ kg$$

$$\Delta E = \Delta mc^2 = -4.48 \times 10^{-13}\ J = -2.79\ MeV$$

(c) What will be the initial activity of 1.0 g of $^{90}$Sr released into the environment, in disintegrations per second?

$$A = kN \qquad k = \frac{\ln 2}{t_{1/2}} \qquad N = \frac{m}{M} \cdot N_A$$

$$A = \frac{\ln 2}{28.1\,yr}\left(\frac{1.0g}{90.g/mol}\right) 6.022 \times 10^{23}\ mol^{-1} = 1.65 \times 10^{20}\ yr^{-1}$$

$$= 5.23 \times 10^{12}\ s^{-1}$$

(d) What activity will the material from part (c) show after 100 years?

$$A_2 = A_1 e^{-kt} = (5.23 \times 10^{12}\ s^{-1}) \exp\left(-100yr\left(\frac{\ln 2}{28.1yr}\right)\right)$$

$$= 4.44 \times 10^{11}\ s^{-1}$$

**5. (5 points)** The solar system abundances of the elements Li, Be, and B are four to seven orders of magnitude lower than those of the elements that immediately follow them: C, N, and O. Explain.

There is no synthetic route to Li, Be, and B in main sequence stars.

Most Li, Be, and B was created in trace amounts during the Big Bang.

**6. (5 points each)** Complete and balance the following equations for nuclear reactions that are thought to take place in stars:

(a) $2\ {}^{12}_{6}C \rightarrow ? + {}^{1}_{0}n$

$$2\ {}^{12}_{6}C \rightarrow {}^{1}_{0}n + {}^{23}_{12}Mg$$

(b) $? + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$

$${}^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{12}_{6}C + {}^{4}_{2}He$$

7. **(5 points each)**

(a) Explain why elements heavier than $^{56}Fe$ are not synthesized in normal stars.

$^{56}Fe$ has the most stable nucleus (highest binding energy per nucleon). Producing heavier elements by fusion is endothermic.

(b) Write the net equation for the fusion reaction that powers our sun.

$$4\ {}^{1}H \rightarrow {}^{4}_{2}He + 2\ {}^{0}_{1}e^{+} + 2\nu_e + \gamma \text{ (non-stoich.)}$$