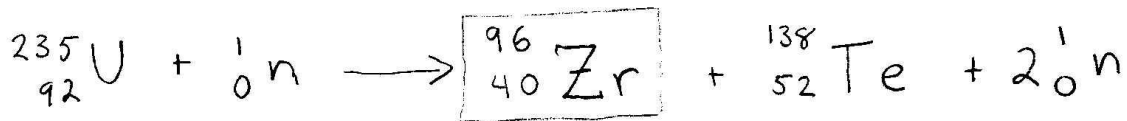
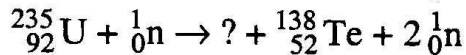


## 1. (5 points each)

a) Complete and balance the equation for the neutron-induced fission of uranium.



b) Calculate the energy liberated in this reaction (kJ/mol). Use attached table.

m)c<sup>2</sup>

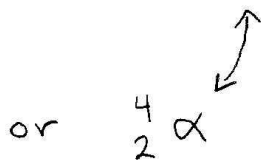
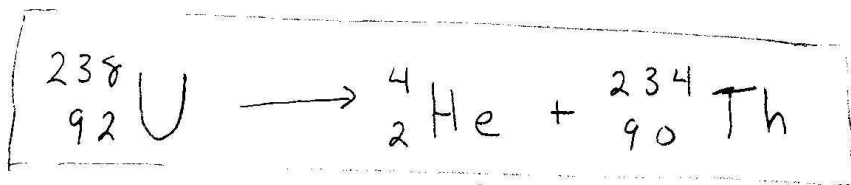
$$\Delta m = m({}_{92}^{235}\text{U} + {}_0^1\text{n}) - m({}_{40}^{96}\text{Zr} + {}_{52}^{138}\text{Te} + 2{}_0^1\text{n})$$

$$= [235.043925 + 1.00866490 - 95.9083 - 137.9292 - 2 \times 1.00866490] \text{ (u)}$$

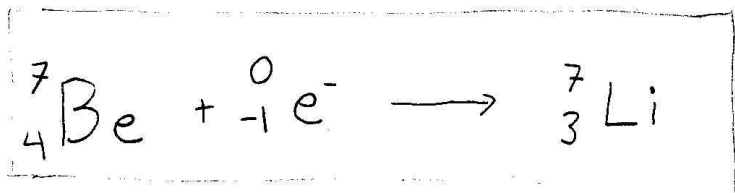
$$= 0.1978 \text{ u} \left( \frac{1.66 \times 10^{-27} \text{ kg}}{1 \text{ u}} \right) = 3.28 \times 10^{-28} \text{ kg}$$

$$= (3.28 \times 10^{-28} \text{ kg}) (3 \times 10^8 \frac{\text{m}}{\text{s}})^2 = 2.952 \times 10^{-11} \text{ J}$$

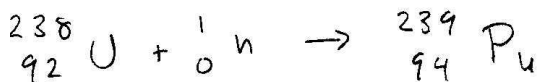
$$= (2.952 \times 10^{-11} \text{ J}) \left( \frac{1 \text{ kJ}}{1000 \text{ J}} \right) \left( \frac{6.02 \times 10^{23}}{1 \text{ mole}} \right) = 1.77 \times 10^{10} \frac{\text{kJ}}{\text{mol}} = \boxed{1.8 \times 10^{10} \frac{\text{kJ}}{\text{mol}}}$$

c) Write the balanced equation for  $\alpha$  decay of  ${}_{92}^{238}\text{U}$ .

d) Write the balanced equation for electron capture by beryllium-7.



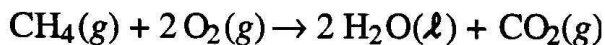
e) Explain the concept of a breeder reactor (showing the relevant nuclear reactions) and how this could become a major long-term energy supply.



A breeder reactor "produces more Fuel than it consumes." The fission of  ${}_{94}^{239}\text{Pu}$  releases energy and on average 2.5 neutrons. Those neutrons can then go on to convert  ${}_{92}^{238}\text{U}$  (which is normally non fissionable) to  ${}_{94}^{239}\text{Pu}$  which can fission and generate energy. On average

${}_{92}^{238}\text{U}$  is converted to  ${}_{94}^{239}\text{Pu}$  than  ${}_{94}^{239}\text{Pu}$  is consumed. Thus, more fuel is produced than consumed.

2. (5 points each) Consider the following chemical reaction as a source of abundant clean energy for the world:



$$\Delta H^\circ = -890\text{kJ/mole}$$

$$\Delta G^\circ = -818\text{kJ/mole}$$

a) Calculate the maximum possible efficiency for using this reaction in an internal combustion engine operating between temperatures of 2000K and 1000K with a compression ratio of 10 (assume it is an ideal heat engine).

$$\epsilon_{\text{max}} = \frac{W_{\text{out}}}{q_{\text{in}}} = \frac{T_{\text{H}} - T_{\text{C}}}{T_{\text{H}}} = \frac{(2000\text{K} - 1000\text{K})}{(2000\text{K})}$$

$$= 0.5 = 50\%$$

b) Calculate the maximum power that would be available from this heat engine if it operates at 10 cycles per second with a total of one mole of ideal gas as the working fluid.

$$P = \text{work}/\text{time} \quad \frac{\text{work}}{\text{cycle}} = -nR(T_H - T_C) \ln\left(\frac{V_A}{V_B}\right)$$

$$= -(1\text{mol})(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(2000\text{K} - 1000\text{K}) \ln(10)$$

$$= 19145 \frac{\text{J}}{\text{cycle}}$$

$$P = \frac{\text{work}}{\text{cycle}} \times \frac{10 \text{ cycles}}{\text{sec}} = 19145 \frac{\text{J}}{\text{cycle}} \times \frac{10 \text{ cycles}}{\text{sec}} = 191450 \frac{\text{J}}{\text{s}} = \boxed{190 \text{ kW}}$$

c) Calculate the net heat absorbed by this engine in one cycle.

$$q_{\text{in}} = \frac{W_{\text{out}}}{\epsilon}$$

$$= \frac{19145 \text{ J}}{0.5} = 38290 \text{ J}$$

$$= \boxed{38 \text{ kJ}}$$

- or -

$$\Delta E = 0 \text{ for 1 cycle}$$

$$\Delta E = q + w$$

$$q = -w$$

$$= 19145 \text{ J}$$

$$= \boxed{19 \text{ kJ}}$$

d) Calculate the maximum electrical work obtainable from a  $\text{CH}_4/\text{O}_2$  fuel cell operating at standard conditions.

$$W_{\text{max}} = -\Delta G$$

at standard conditions

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

$$= 818 \frac{\text{kJ}}{\text{mol}} = \boxed{820 \frac{\text{kJ}}{\text{mol}}}$$

e) Calculate the maximum electrical power obtainable from the fuel cell above if it can produce a current of 1.0 amperes.

$$P = \epsilon \cdot i$$

$$= (1.06 \text{ Volt})(1.0 \text{ Amp}) = \boxed{1.0 \text{ W}}$$

$$\Delta G = -nF\epsilon$$

$$\epsilon = -\frac{\Delta G}{nF} = \frac{-818 \text{ kJ}}{(8 \text{ mol } e^-)(96485 \frac{\text{C}}{\text{mol } e^-})} = 1.06 \frac{\text{J}}{\text{C}}$$

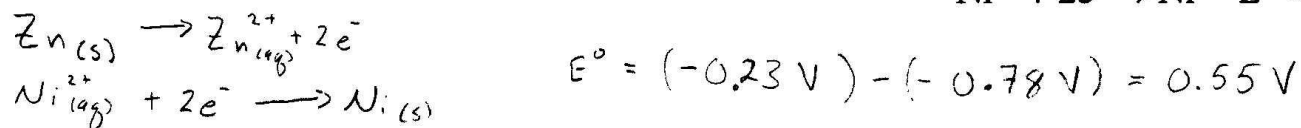
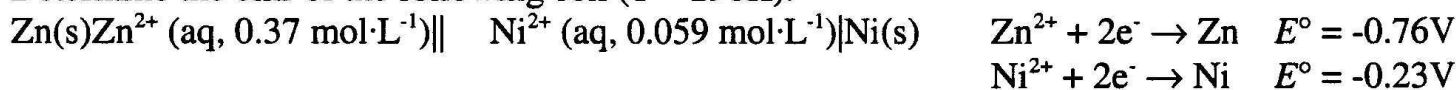
f) Calculate the maximum total work obtainable from this reaction under standard conditions (hint: use ideal gas approximation).

$$\begin{aligned}
 W_{\max} &= -\Delta A^{\circ} \\
 &= -(\Delta G^{\circ} - \Delta(PV)) \\
 &= -(-818 \times 10^3 + 4955) \text{ J/mole} \\
 &= 813045 \text{ J/mole} = \boxed{810 \frac{\text{kJ}}{\text{mol}}}
 \end{aligned}$$

$$\begin{aligned}
 \Delta(PV) &= \Delta(n)RT \\
 &= (1\text{mol} - 3\text{mol})(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298\text{K}) \\
 &= -4955 \text{ J/mole}
 \end{aligned}$$

### 3. (5 points each)

a) Determine the emf of the following cell ( $T = 298\text{K}$ ):



$$E = E^{\circ} - \frac{RT}{nF} \ln Q \quad \text{or} \quad \left[ E = E^{\circ} - \frac{0.05916}{n} \log Q \right]$$

$$\begin{aligned}
 &= (0.53 \text{ V}) - \frac{(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298\text{K})}{(2 \text{ mol e}^{-})(96485 \frac{\text{C}}{\text{mol e}^{-}})} \ln \left( \frac{0.37 \text{ M}}{0.059 \text{ M}} \right) = 0.53 \text{ V} - 0.024 \\
 &= 0.506 \text{ V}
 \end{aligned}$$

$$= \boxed{0.53 \text{ V}}$$

b) Calculate the maximum electrical work that can be produced by this cell.

$$W_{\max} = -\Delta G$$

$$= nFE$$

$$= (2 \frac{\text{mol e}^{-}}{\text{mol}})(96485 \frac{\text{C}}{\text{mol e}^{-}})(0.53 \text{ V}) = 102274 \text{ J/mol}$$

$$= \boxed{100 \frac{\text{kJ}}{\text{mol}}}$$

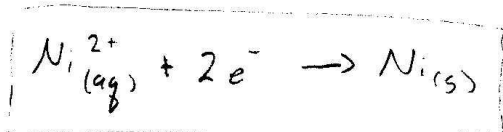
- c) Calculate the reactant quotient (Q) for this cell.



$$Q = \frac{[\text{Zn}^{2+}]}{[\text{Ni}^{2+}]} = \left( \frac{0.37 \text{ M}}{0.059 \text{ M}} \right) = 6.271$$

$$= \boxed{6.3}$$

- d) Write the balanced half-reaction occurring at the cathode and calculate the cathode potential.

cathode  $\Rightarrow$  reduction

$$E = E^{\circ} - \frac{RT}{nF} \ln Q$$

$$= (-0.23 \text{ V}) - \frac{(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298 \text{ K})}{(2 \text{ mole } e^{-})(96485 \frac{\text{C}}{\text{mole } e^{-}})} \ln \left( \frac{1}{0.05} \right)$$

$$= (-0.23 \text{ V}) - (0.036 \text{ V})$$

$$= -0.266 \text{ V}$$

$$= \boxed{-0.27 \text{ V}}$$

## 4. (10+10+5 points)

- a) The energy needed for a person of mass
- $m$
- to climb through a height
- $h$
- on the surface of Earth is equal to
- $mgh$
- . What is the minimum mass of sucrose (MW = 342 g/mole) a person of mass 80 kg must metabolize to provide the energy needed to climb through 100 m? The free energy of combustion of sucrose is
- $-5796 \text{ kJ}\cdot\text{mol}^{-1}$
- .

$$\text{mass sucrose} = \left( \frac{342 \text{ g sucrose}}{\text{mole sucrose}} \right) \left( \frac{1 \text{ mole sucrose}}{5796 \times 10^3 \text{ J}} \right) (\text{work})$$

$$= (342) \left( \frac{1}{5796000} \right) (78400) = 4.626 \text{ g}$$

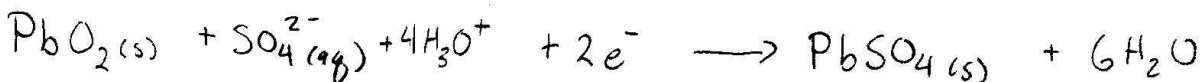
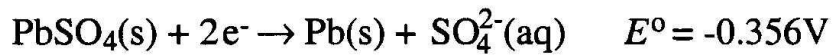
$$= \boxed{4.6 \text{ g sucrose}}$$

$$\text{work} = mgh$$

$$= (80 \text{ kg}) \left( 9.8 \frac{\text{m}}{\text{s}^2} \right) (100 \text{ m})$$

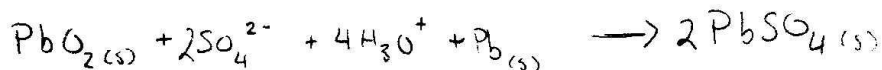
$$= 78400 \text{ J}$$

The relevant half-reactions for the lead-acid battery (written as reductions) are:



$$([\text{H}^+] = [\text{SO}_4^{2-}] = 5.0 \text{ M})$$

b) Calculate the voltage at the terminals of a fully charged battery consisting of 6 cells in series at 298K.



$$Q = \left[ \frac{1}{[\text{SO}_4^{2-}]^2 [\text{H}_3\text{O}^+]^4} \right]$$

$$= \frac{1}{5^6} = 6.4 \times 10^{-5}$$

1 cell:

$$E = E^\circ - \frac{RT}{nF} \ln Q$$

$$= [(1.685\text{V}) - (-0.356\text{V})] - \frac{(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298\text{K})}{(2\text{mol e}^-)(96485 \frac{\text{C}}{\text{mol e}^-})} \ln(6.4 \times 10^{-5})$$

$$= [2.041\text{V} - (-0.124\text{V})] = 2.165\text{V}$$

6 cells

$$E = 6(2.165\text{V}) = 12.99\text{V}$$

$$\boxed{E = 13.0\text{V}}$$

c) When the battery is being charged (acting as an electrolytic cell), which is the anode reaction?

Anode  $\Rightarrow$  oxidation

charging  $\Rightarrow$  reverse of reduction

$\Rightarrow$

