1. (5 points each)

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

$^{235}_{92}U + ^{1}_{0}n \rightarrow ? + ^{138}_{52}Te + 2\,^{1}_{0}n$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow \boxed{^{96}_{40}Zr} + ^{138}_{52}Te + 2\,^{1}_{0}n$$

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

$(\Delta m)c^2$

$$\Delta m = m(^{235}_{92}U + ^{1}_{0}n) - m(^{96}_{40}Zr + ^{138}_{52}Te + 2\,^{1}_{0}n)$$

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

$$= 0.1978\,u \left(\frac{1.66\times10^{-27}\,kg}{1\,u}\right) = 3.28\times10^{-28}\,kg$$

$$= (3.28\times10^{-28}\,kg)(3\times10^{8}\,\tfrac{m}{s})^2 = 2.952\times10^{-11}\,J$$

$$= (2.952\times10^{-11}\,J)\left(\frac{1\,kJ}{1000\,J}\right)\left(\frac{6.02\times10^{23}}{1\,mole}\right) = 1.77\times10^{10}\,\frac{kJ}{mol} = \boxed{1.8\times10^{10}\,\frac{kJ}{mol}}$$

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

$$\boxed{^{238}_{92}U \longrightarrow ^{4}_{2}He + ^{234}_{90}Th}$$

or $^{4}_{2}\alpha$

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

$$^{7}_{4}Be + ^{0}_{-1}e^{-} \longrightarrow ^{7}_{3}Li$$

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

$$^{239}_{94}Pu + ^{1}_{0}n \longrightarrow \text{Fission Products} + \sim 2.5\, ^{1}_{0}n + \text{Energy}$$

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{94}Pu$$

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

$$CH_4(g) + 2\,O_2(g) \rightarrow 2\,H_2O(\ell) + CO_2(g)$$

$\Delta H° = -890\text{kJ/mole}$
$\Delta G° = -818\text{kJ/mole}$

a) Calculate the maximum possible <u>efficiency</u> 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).

$$\mathcal{E}_{max} = \frac{W_{out}}{q_{in}} = \frac{T_H - T_c}{T_H} = \frac{(2000K - 1000K)}{(2000K)}$$

$$= 0.5 = 50\%$$

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.

$P = \text{work}/\text{time}$ $\quad \frac{\text{work}}{1\text{cycle}} = -nR(T_H - T_C)\ln\left(\frac{V_A}{V_B}\right)$

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

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

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

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

$q_{in} = \frac{W_{out}}{\varepsilon}$

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

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

-or-

$\Delta E = 0$ 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 CH_4/O_2 fuel cell operating at standard conditions.

$W_{max} = -\Delta G$

at standard conditions

$= -\Delta G^o$

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

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

$P = \mathcal{E} \cdot i$

$\Delta G = -nF\mathcal{E}$

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

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

$= \boxed{1.0\text{ W}}$

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

$W_{Max} = -\Delta A^\circ$

$= -(\Delta G^\circ - \Delta(PV))$

$= -(-818\times10^3 + 4955)\ J/mole$

$= 813045\ J/mole = \boxed{810\ kJ/mol}$

$\Delta(PV) = \Delta(n)RT$

$= (1mol - 3mol)(8.3145\ \frac{J}{mol\cdot K})(298K)$

$= -4955\ J/mole$

3. (5 points each)

a) Determine the emf of the following cell (T = 298K):

$Zn(s)Zn^{2+}$ (aq, 0.37 mol·L^{-1})|| Ni^{2+} (aq, 0.059 mol·L^{-1})|Ni(s)

$Zn^{2+} + 2e^- \rightarrow Zn \quad E^\circ = -0.76V$

$Ni^{2+} + 2e^- \rightarrow Ni \quad E^\circ = -0.23V$

$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^-$

$Ni^{2+}_{(aq)} + 2e^- \rightarrow Ni_{(s)}$

$E^\circ = (-0.23\ V) - (-0.78\ V) = 0.55\ V$

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

$= (0.55\ V) - \frac{(8.3145\ \frac{J}{mol\cdot K})(298K)}{(2 mol\ e^-)(96485\ \frac{C}{mol\ e^-})}\ln\left(\frac{0.37\ M}{0.059\ M}\right) = 0.55V - 0.024$

$= 0.526\ V$

$= \boxed{0.53\ V}$

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

$W_{max} = -\Delta G$

$= nFE$

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

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

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

$Zn_{(s)} + Ni^{2+}_{(aq)} \longrightarrow Zn^{2+}_{(aq)} + Ni_{(s)}$

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

$= \boxed{6.3}$

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

cathode => reduction

$\boxed{Ni^{2+}_{(aq)} + 2e^- \longrightarrow Ni_{(s)}}$

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

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

$= (-0.23 V) - (0.036 V)$

$= -0.266\ V$

$= \boxed{-0.27 V}$

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 kJ·mol^{-1}.

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

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

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

work = mgh

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

$= 78400\ J$

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

$PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$ $E^o = -0.356V$

~~$PbSO_2(s) + 4\ H_3O^+ + 2e^- \rightarrow PbSO_4(s) + 6\ H_2O$~~ $E^o = +1.685V$

$PbO_{2(s)} + SO_{4\,(aq)}^{2-} + 4H_3O^+ + 2e^- \longrightarrow PbSO_{4\,(s)} + 6H_2O$

$([H^+] = [SO_4^{2-}] = 5.0\ \underline{M})$

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

$PbO_{2(s)} + 2SO_4^{2-} + 4H_3O^+ + Pb_{(s)} \longrightarrow 2PbSO_{4\,(s)}$

$Q = \left[\dfrac{1}{[SO_4^{2-}]^2[H_3O^+]^4}\right] = \dfrac{1}{5^6} = 6.4\times10^{-5}$

1 cell:

$E = E^o - \dfrac{RT}{nF}\ln Q$

$= [(1.685V) - (-0.356V)] - \dfrac{(8.3145\frac{J}{mol\cdot k})(298k)}{(2 mol\ e^-)(96485\frac{c}{mol\ e^-})}\ln(6.4\times10^{-5})$

$= [2.041V - (-0.124V)] = 2.165\ V.$

6 cells

$E = 6(2.165\ V) = 12.99\ V$

$\boxed{E = 13.V}$

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

Anode => oxidation

charging => reverse of reduction

=>

$PbSO_{4\,(s)} + 6H_2O \longrightarrow PbO_{2(s)} + SO_{4\,(aq)}^{2-} + 4H_3O^+ + 2e^-$