

Chemistry 1B, Exam II
March 8, 2007
Professor R.J. Saykally

Name KEY

TA _____

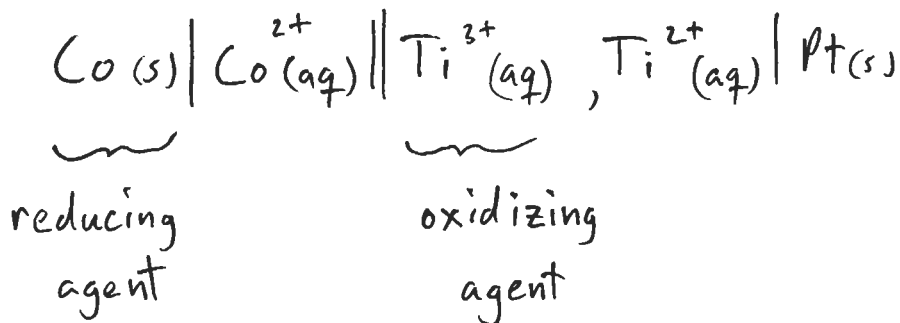
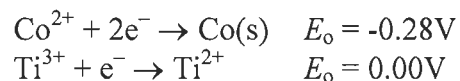
1. (10) _____
2. (10) ~~_____~~
3. (20) _____
4. (20) _____
5. (25) _____
6. (15) _____

TOTAL EXAM SCORE (100) _____

Rules:

- Work all problems to 2 significant figures
- No lecture notes or books permitted
- No word processing calculators
- Time: 90 minutes
- Show all work to get partial credit
- Periodic Table, Tables of Physical Constants, and Conversion Factors included

1. (10 points) Suppose that the following redox couple is joined to form a galvanic cell that generates a current under standard conditions. Identify the oxidizing agent and the reducing agent, write a cell diagram, and calculate the standard cell emf.



$$E^\circ = 0.00\text{V} - (-0.28\text{V}) = \boxed{0.28\text{V}}$$

2. (2 points each) The total world energy consumption is 14 TW, which is increasing

at a rate of 5% per year, corresponding to a doubling time of 14 years.

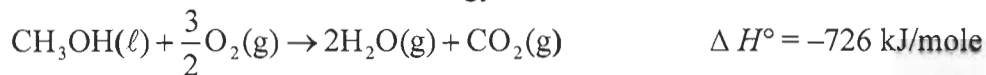
Transportation accounts for 27 % of this energy use. A typical gasoline auto engine operates at a

maximum efficiency near 30-50%, wasting much of this energy.

thermal

14% also accepted

3. (5 points each) Consider the following chemical reaction (note: 6 electrons are transferred) as a potential source of abundant clean energy for the world:



Partial pressures are 1 bar

$$\begin{aligned} S^\circ(\text{H}_2\text{O}(\text{g})) &= 189 \text{ JK}^{-1} \text{ mole}^{-1} \\ S^\circ(\text{CO}_2(\text{g})) &= 198 \text{ JK}^{-1} \text{ mole}^{-1} \\ S^\circ(\text{O}_2(\text{g})) &= 205 \text{ JK}^{-1} \text{ mole}^{-1} \\ S^\circ(\text{CH}_3\text{OH}(\ell)) &= 127 \text{ JK}^{-1} \text{ mole}^{-1} \end{aligned}$$

a) Calculate the maximum possible efficiency for using this reaction in an internal combustion engine operating between temperatures of 2800K and 800K with a compression ratio of 15.

$$\text{eff} = 1 - \frac{T_c}{T_h} = 1 - \frac{800\text{K}}{2800\text{K}} = 0.714$$

$$\boxed{71.4\%}$$

b) Calculate the maximum electrical work obtainable from a methanol fuel cell operating at 1000K.

$$\begin{aligned} w_{e_{\max}} &= \Delta G = \Delta H - T\Delta S \\ &= -726 \text{ kJ/mol} - (1000\text{K}) \left(2(189 \text{ J/mol K}) + 198 \text{ J/mol K} \right. \\ &\quad \left. - 127 \text{ J/mol K} - \frac{3}{2}(205 \text{ J/mol K}) \right) \\ &= \boxed{-868 \text{ kJ/mol}} \end{aligned}$$

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

$$\begin{aligned} P &= I E \\ \Delta G^\circ &= -n F E^\circ \\ E^\circ &= -\frac{\Delta G^\circ}{nF} = \frac{-(-868 \text{ kJ/mol})}{6(96485 \text{ C/mol } e^-)} = 1.50\text{V} \\ E &= E^\circ - \frac{RT}{nF} \ln Q \\ Q &= \frac{(1 \text{ bar})^2 (1 \text{ bar})}{(1 \text{ bar})^{3/2}} = 1 \Rightarrow \ln Q = 0 \\ &\Rightarrow E = E^\circ \\ P &= (1\text{A})(1.5\text{V}) = \boxed{1.5\text{W}} \end{aligned}$$

- d) Calculate the maximum total work obtainable from this reaction at 1000K and 1 atm pressure (hint: use ideal gas approximation).

$$W_{\text{Tot}} = W_{\text{elec}} + W_{\text{pv}}$$

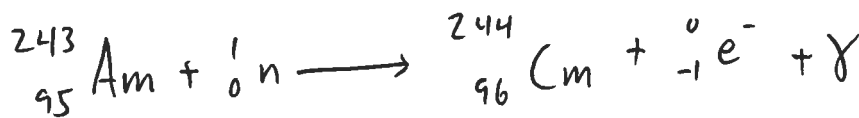
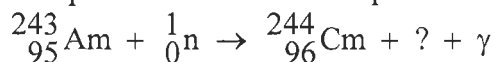
$$W_{\text{pv}} = P \Delta V = \Delta n RT = (1.5 \text{ mol})(8.314 \text{ J/mol K})(1000 \text{ K})$$

$$= 12.5 \text{ kJ/mol}$$

$$W_{\text{Tot}} = -868 \text{ kJ/mol} - 12.5 \text{ kJ/mol} = \boxed{-880 \text{ kJ/mol}}$$

4. (5 points each)

- a) Complete and balance the equation for the nuclear reaction:



or β^-

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

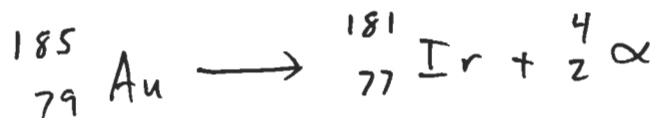
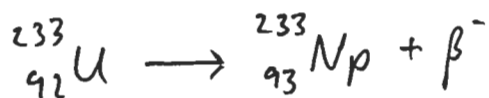
$$\Delta m = (244.063 \text{ u})(1.6605 \times 10^{-27} \text{ kg/u}) + 9.109390 \times 10^{-31} \text{ kg}$$

$$- \left[(243.061 \text{ u})(1.6605 \times 10^{-27} \text{ kg/u}) + 1.674929 \times 10^{-27} \text{ kg} \right]$$

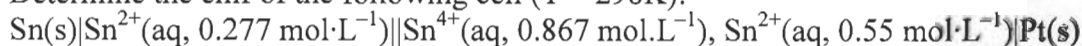
$$= -1.08 \times 10^{-29} \text{ kg} \Rightarrow E = \Delta m c^2 = (-1.08 \times 10^{-29} \text{ kg})(3 \times 10^8 \text{ m/s})^2$$

$$\boxed{E = 5.83 \times 10^8 \text{ kJ/mol}}$$

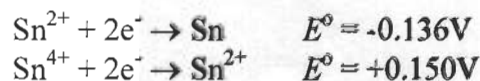
- c) Write the balanced equation for α decay of gold-185.

or α or He^{2+} d) Write the balanced equation for the β^- decay of uranium -233.or ${}_{-1}^0e^-$

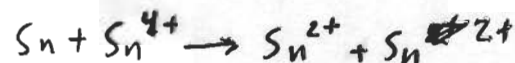
5. (10+5+10 points)

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

$$E^\circ = 0.150\text{V} - (-0.136\text{V}) = 0.286\text{V}$$



$$E = E^\circ - \frac{RT}{2F} \ln \frac{[\text{Sn}^{2+}][\text{Sn}^{2+}]}{[\text{Sn}^{4+}]}$$



$$= 0.286\text{V} - \frac{(8.314 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1})(298\text{K})}{2(96485 \text{ C}\cdot\text{mol}^{-1})} \ln \frac{(0.277)(0.55)}{(0.867)}$$

$$\Rightarrow E = \cancel{0.308} \boxed{0.31\text{V}}$$

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

$$\Delta G = -nFE$$

$$= -2 (96485 \text{ C}\cdot\text{mol}^{-1})(0.31\text{V})$$

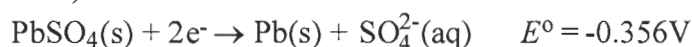
$$\Delta G = \boxed{-60.3 \text{ kJ/mol}}$$

c) Calculate the equilibrium constant for the overall cell reaction.

$$\ln K = \frac{nFE^\circ}{RT} = \frac{2 (96485 \text{ C}\cdot\text{mol}^{-1})(0.286\text{V})}{(8.314 \text{ J/mol}\cdot\text{K})(298\text{K})} = 22.3$$

$$\Rightarrow \boxed{K = 4.7 \times 10^9}$$

6. (10+5 points) The relevant half-reactions for the fully charged lead-acid battery (written as reductions) are:



$$([\text{H}^+] = [\text{SO}_4^{2-}] = 6.0 \text{ M})$$

a) Calculate the maximum electrical power available from this battery if a current of 120 amps is produced at 298K.

$$E^\circ = 1.685\text{V} - (-0.356\text{V}) = 2.041\text{V}$$

$$E = E^\circ - \frac{RT}{nF} \ln Q = 2.041\text{V} - \frac{(8.314)(298)}{2(96485)} \ln \left(\frac{1}{6^4 \cdot 6} \right)$$

$\text{H}^+ \quad \text{SO}_4^{2-}$

$$E = 2.156\text{V}$$

$$P = IE = (120\text{A})(2.156\text{V}) = \boxed{260\text{W}}$$

b) Estimate the energy equivalent (EE) for this battery (assume it is all Pb).

$$\Delta G = -nFE = -2 (96485 \text{ C}\cdot\text{mol}^{-1})(2.156 \text{ V})$$

$$= 416 \text{ kJ/mol Pb}$$

$$\left(\frac{416 \text{ kJ}}{1 \text{ mol Pb}} \right) \left(\frac{1 \text{ mol Pb}}{207.2 \text{ g Pb}} \right) = 2.0 \times 10^3 \text{ kJ/kg Pb}$$