

Chemistry 1B, Exam II  
March 18, 2009  
Professor R.J. Saykally

Name KEY  
TA \_\_\_\_\_

1. (10) \_\_\_\_\_
2. (10) \_\_\_\_\_
3. (40) \_\_\_\_\_
4. (20) \_\_\_\_\_
5. (10) \_\_\_\_\_
6. (10) \_\_\_\_\_

TOTAL EXAM SCORE (100) \_\_\_\_\_

**Rules:**

- Work all problems to 3 significant figures
- No lecture notes or books permitted
- No word processing calculators
- Time: 50 minutes
- Show all work to get partial credit
- Periodic Table, Tables of Physical Constants, Conversion Factors, and Key Equations included

1. (10 points) A thermodynamic engine operates cyclically and reversibly between two temperature reservoirs, absorbing heat from the high-temperature bath at 450 K and discharging heat to the low-temperature bath at 300 K. How much heat is discarded to the low-temperature bath if 1500 J of heat is absorbed from the high-temperature bath during each cycle?

$$\frac{q_H}{T_H} = \frac{q_L}{T_L} \rightarrow q_L = \frac{q_H}{T_H} \cdot T_L$$

$$= \frac{1500 \text{ J} \cdot 300 \text{ K}}{450 \text{ K}}$$

$$= \boxed{1000 \text{ J}}$$

$$(1.00 \times 10^3 \text{ J} \sim 3 \text{ sf})$$

2. (10 points) The strongest known chemical bond is that in carbon monoxide, CO, with bond enthalpy of  $1.05 \times 10^3 \text{ kJ mol}^{-1}$ . Furthermore, the entropy increase in a gaseous dissociation of the kind  $\text{AB} \rightleftharpoons \text{A} + \text{B}$  is about  $110 \text{ J mol}^{-1} \text{ K}^{-1}$ . These factors establish a temperature above which there is essentially no chemistry of molecules. Show why this is so, and find the temperature.

$$\Delta G = \Delta H - T\Delta S = 0 \quad @ \text{ equilibrium}$$

$\nwarrow$  above this temperature, the forward rxn will dominate  $\text{AB} \rightarrow \text{A} + \text{B}$  ( $\Delta G < 0$ )

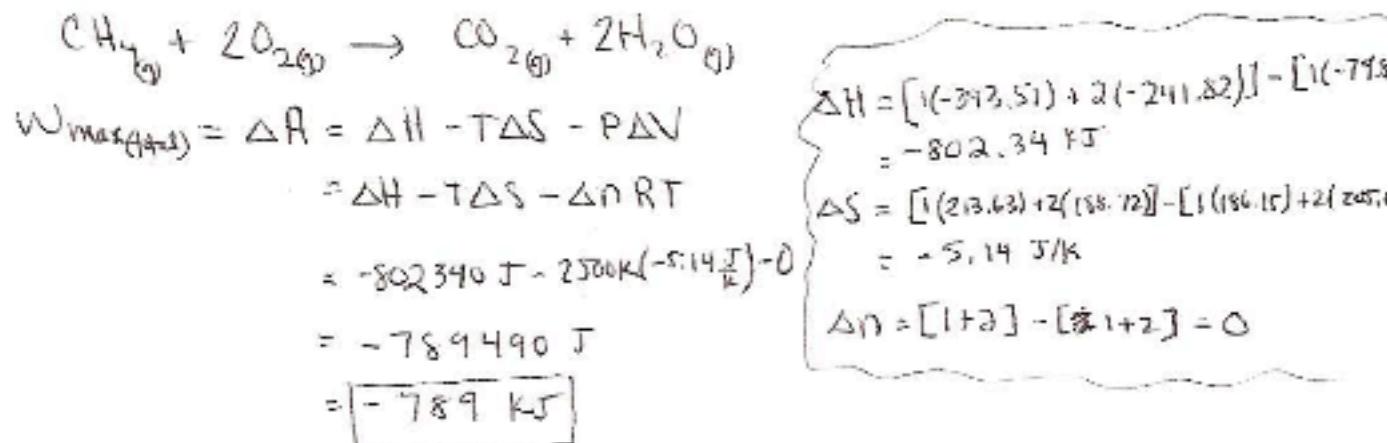
$$T = \frac{\Delta H}{\Delta S} = \frac{1.05 \times 10^3 \text{ kJ/mol}}{0.110 \text{ kJ/mol} \cdot \text{K}} = 9545 \text{ K}$$

$$= \boxed{9500 \text{ K}}$$

$$(9550 \text{ K} \sim 3 \text{ sf.})$$

3. (8 points each) Consider the combustion of methane ( $\text{CH}_4$ ) occurring at 2500 K:

A) Calculate the total maximum work that can be extracted from the reaction.



B) If this reaction is used to drive an internal combustion engine wherein the exhaust is removed to a cold reservoir at  $T = 1000 \text{ K}$ , calculate the maximum work that this engine could perform

$$W_{\text{max}} = W_{\text{max(total)}} \times \epsilon$$

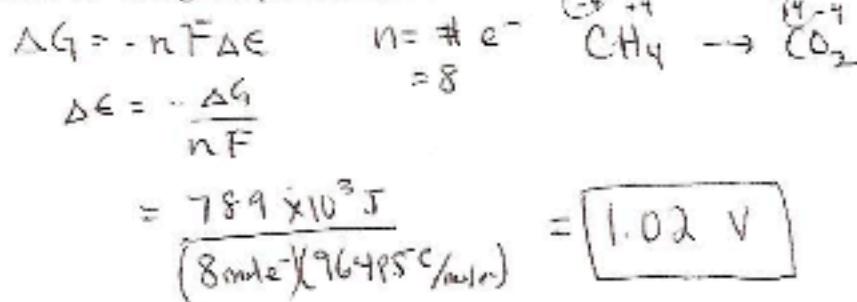
$$= W_{\text{max(total)}} \times 1 - \frac{T_L}{T_H}$$

$$= -789 \text{ kJ} \left(1 - \frac{1000 \text{ K}}{2500 \text{ K}}\right) = \boxed{-473 \text{ kJ}}$$

C) Calculate the electrical work that could be extracted from the reaction in a fuel cell (at 2500 K).

$$W_{\text{max(elec)}} = \Delta G = \Delta H - T\Delta S = \boxed{-789 \text{ kJ}} \quad (\text{same as part(a)})$$

D) Calculate the voltage output of this fuel cell.



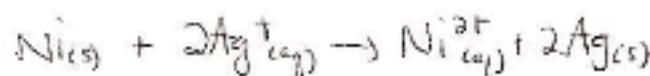
E) If this fuel cell can produce 50 amps of current, what is the power that it can produce?

$$P = I \Delta E = (50 \frac{\text{A}}{\text{s}})(1.02 \frac{\text{V}}{\text{s}}) = \boxed{51 \text{ W}}$$

## 4. (10+10 points)

- A) A  $\text{Ni}|\text{Ni}^{2+}||\text{Ag}^+|\text{Ag}$  galvanic cell is constructed in which the standard cell voltage is 1.03 V. Calculate the free energy change at 25°C when 1.00 g of silver plates out, if all concentrations remain at their standard value of 1 M throughout the process.

$$\Delta G = -n F \Delta E^\circ$$



$$= -(2 \text{ mol e}^-)(96485 \frac{\text{C}}{\text{mol e}^-})(1.03 \text{ V})$$

$$= -199 \text{ kJ per mol rxn}$$

$$\frac{-199 \text{ kJ}}{\text{mol rxn}} \cdot \frac{1 \text{ mol rxn}}{2 \text{ mol Ag}} \cdot \frac{1 \text{ mol Ag}}{107.87 \text{ g Ag}} \times 1.00 \text{ g Ag} = -0.922 \text{ kJ}$$

$$= \boxed{-922 \text{ J}}$$

- B) What is the maximum electrical work done by the cell on its surroundings during this experiment if the ion concentrations drop to 0.20 M?

$$\Delta E = \Delta E^\circ - \frac{0.0592}{n} \log Q \quad Q = \frac{[\text{Ni}^{2+}]}{[\text{Ag}^+]^2}$$

$$= 1.03 \text{ V} - \frac{0.0592}{2} \log \frac{(0.2 \text{ M})}{(0.2 \text{ M})^2}$$

$$= 1.01 \text{ V}$$

$$\Delta G = -n F \Delta E = -(2 \text{ mol e}^-)(96485 \frac{\text{C}}{\text{mol e}^-})(1.01 \text{ V})$$

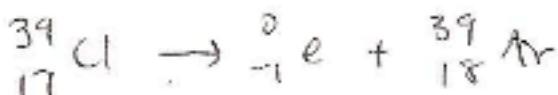
$$= \boxed{-195 \text{ kJ}}$$

5. (2 points each) Briefly rationalize the following observations regarding the cosmic abundance of the elements:

- A) Even Z nuclei are more abundant than odd Z nuclei nuclear shell theory  
(spin pairing of protons)
- B) H and He comprise 88.6% and 11.3% of the atoms in the Universe originated  
in the big bang
- C) In the lighter elements, those with mass number divisible by 4 are more abundant formed  
from  $^3_2$ He fusion cycle
- D)  $^{56}$ Fe is considerably more abundant than adjacent mass number elements it has  
the most stable nucleus
- E) Li, Be, and B are very rare compared to neighboring elements very short lived  
and used to create heavier elements

6. (5 points each) Write balanced equations that represent the following nuclear reactions.

- A) Beta emission by  $^{37}_{17}\text{Cl}$



- B) Alpha emission by  $^{224}_{88}\text{Ra}$

