Unit 4: AP Free Response Practice #3 [LTF Free Response #2, 10 points]

$$N_2(g) + 3\,H_2(g) \leftrightarrow 2\,NH_3(g) \qquad \Delta G^\circ_{rxn} = -34.1\ \text{kJ mol}^{-1}$$

3. The following questions relate the the synthesis reaction represented by the chemical equation above.

   a. Is the reaction ~~spontaneous or non-spontaneous~~ thermodynamically favorable under standard conditions at 298 K? Justify your answer. [*1 point*]

   b. In terms of the equilibrium constant, K, for the above reaction at 25°C

      i. Predict whether K will be greater than, less than, or equal to one. Justify your choice. [*1 point*]

      ii. Calculate its value. [*2 points*]

   c. Given the following data, determine the ΔH° for the above reaction. [*2 points*]

Substance	ΔH_f° (kJ mol^{-1})
$NH_3(g)$	-46.1

   d. In terms of the standard entropy change, ΔS°

      i. Predict the sign of ΔS° for the above reaction. Justify your answer. [*1 point*]

      ii. Calculate the value of ΔS° for the above reaction at 25°C. [*1 point*]

   e. Using the data in the table below and the enthalpy of reaction, ΔH°_{rxn} determined in part (c), calculate the approximate bond energy of the nitrogen-hydrogen bond in ammonia. [*2 points*]

Bonds	Approximate Bond Energy (kJ mol^{-1})
N – H	???
H – H	430
N ≡ N	960

a) Spontaneous! (thermodynamically favorable) b/c $-\Delta G$

b)(i) $K > 1$, b/c ΔG is negative, products are favored.

(ii) $\Delta G^\circ = -RT \ln K \Rightarrow K = e^{-\Delta G/RT}$ (make sure ΔG is in J/mol!)

$= e^{(34{,}100\ J/mol / 8.314\ J/mol\cdot K \times 298)}$

$= e^{13.763} = \boxed{9.49 \times 10^5}$

c) $\Delta H^\circ_{rxn} = \Sigma \Delta H_f^\circ(pr) - \Sigma \Delta H_f^\circ(re)$

$= [2(NH_3)] - [N_2 + 3H_2]$

$= 2(-46.1) - \emptyset = \boxed{-92.2\ kJ/mol\ rxn}$

d)(i) ΔS should be negative, b/c 4 gas particles are forming 2 gas particles

(ii) $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

$$\Rightarrow \Delta S^\circ = \frac{\Delta H^\circ - \Delta G^\circ}{T} = \frac{-92.2\ \text{kJ/mol}_{rxn} - (-34.1\ \text{kJ/mol}_{rxn})}{298\ \text{K}} = \boxed{-0.196\ \text{kJ/mol·K}}$$

(or -196 J/mol·K)

e) $:N\equiv N: + 3(H-H) \longrightarrow 2\left(H-\underset{\displaystyle H}{\overset{\displaystyle \cdot\cdot}{N}}-H\right)$

$\Delta H^\circ_{rxn} = \Sigma BE(re) - \Sigma BE(pr)$

$-92.2 = [1(N\equiv N) + 3(H-H)] - [6(N-H)]$

$= [960 + 3(430)] - 6(N-H)$

$= 2250 - 6(N-H)$

$2342.2 = 6(N-H)$

$BE(N-H) = \boxed{390\ \text{kJ/mol}_{rxn}}$