AP® CHEMISTRY
2003 SCORING GUIDELINES

Question 7

7. Answer the following questions that relate to the chemistry of nitrogen.

(a) Two nitrogen atoms combine to form a nitrogen molecule, as represented by the following equation.

$$2\ N(g) \rightarrow N_2(g)$$

Using the table of average bond energies below, determine the enthalpy change, ΔH, for the reaction.

Bond	Average Bond Energy (kJ mol^{-1})
N — N	160
N ═ N	420
N ≡ N	950

$\Delta H = -950$ kJ The reaction is exothermic because the chemical equation shows the formation of the N ≡ N bond.	1 point for correct sign 1 point for magnitude

(b) The reaction between nitrogen and hydrogen to form ammonia is represented below.

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g) \qquad \Delta H^\circ = -92.2 \text{ kJ}$$

Predict the sign of the standard entropy change, ΔS°, for the reaction. Justify your answer.

ΔS° is negative. There are fewer moles of product gas (2 mol) compared to reactant gases (4 mol), so the reaction is becoming more ordered.	1 point for correct sign 1 point for indicating fewer moles of products compared to reactants (in the gas phase)

(c) The value of ΔG° for the reaction represented in part (b) is negative at low temperatures but positive at high temperatures. Explain.

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ ΔH° and ΔS° are negative. At low temperatures, the $T\Delta S^\circ$ term is smaller than ΔH°, and ΔG° is negative. At high temperatures, the $T\Delta S^\circ$ term is higher than ΔH°, and ΔG° is positive.	1 point each for using $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ to explain the sign of ΔG° at high and low temperatures.

Question 7 (cont'd.)

(d) When $N_2(g)$ and $H_2(g)$ are placed in a sealed container at a low temperature, no measurable amount of NH_3 is produced. Explain.

Even though the reaction is spontaneous at low temperature, the reaction is very slow. The speed of a reaction depends on the fraction of colliding molecules with energy that exceeds the activation energy for the reaction. At low temperature, few reactant particles collide with an energy greater than the activation energy.	1 point for indicating that the frequency of collision (or kinetic energy) of molecules is low at low temperature (thus the rate is slow) 1 point for indicating that at low temperature the kinetic energy will likely be too small to exceed the activation energy