For the reaction $NH_4Cl(s) \longrightarrow NH_3(g) + HCl(g)$, at 298.15 K, $\Delta H^0 = 176$ kJ/mol and $\Delta S^0 = 0.285$ kJ/(mol·K). Calculate ΔG^0, and tell whether this reaction is spontaneous in the forward direction at 298.15 K.

SOLUTION

1 ANALYZE

Given: $\Delta H^0 = 176$ kJ/mol at 298.15 K
$\Delta S^0 = 0.285$ kJ/(mol·K) at 298.15 K
Unknown: ΔG^0 at 298.15 K

2 PLAN

$$\Delta S, \Delta H, T \rightarrow \Delta G$$

The value of ΔG can be calculated according to the following equation.

$$\Delta G^0 = \Delta H^0 - T\Delta S^0$$

3 COMPUTE

$$\Delta G^0 = 176 \text{ kJ/mol} - 298 \text{ K } [0.285 \text{ kJ/(mol·K)}]$$
$$= 176 \text{ kJ/mol} - 84.9 \text{ kJ/mol}$$
$$= 91 \text{ kJ/mol}$$

4 EVALUATE

The answer is reasonably close to an estimated value of 110, calculated as $200 - (300 \times 0.3)$. The positive value of ΔG shows that this reaction does not occur naturally at 298.15 K.

PRACTICE *Answers in Appendix E*

1. For the vaporization reaction $Br_2(l) \longrightarrow Br_2(g)$, $\Delta H^0 = 31.0$ kJ/mol and $\Delta S^0 = 93.0$ J/(mol·K). At what temperature will this process be spontaneous?

extension
Go to **go.hrw.com** for more practice problems that ask you to determine spontaneity based on free-energy changes.

Keyword: HC6NRGX

SECTION REVIEW

1. What kind of enthalpy change favors a spontaneous reaction?

2. What is entropy, and how does it relate to spontaneity of reactions?

3. List several changes that result in an entropy increase.

4. Define *free energy*, and explain how its change is calculated.

5. Explain the relationship between free-energy change and spontaneity of reactions.

6. In the reaction in Sample Problem D, why does the entropy increase?

Critical Thinking

7. **APPLYING MODELS** Most biological enzymes become denatured when they are heated and lose their ability to catalyze reactions. This process (original enzyme $\longrightarrow$ denatured enzyme) is endothermic and spontaneous. Which structure, the original enzyme or the denatured enzyme, is more ordered? Explain your reasoning using thermodynamic concepts.