

Entropy and Gibbs Free Energy

 ΔS , $\Delta G = \Delta H - T\Delta S$ and K

Name _____ Class _____ Date _____

EQUATIONS AND DATA (298.15 K)

$$\Delta S^\circ = \sum nS^\circ(\text{products}) - \sum nS^\circ(\text{reactants}) \cdot \Delta G = \Delta H - T\Delta S \text{ (T in K; } \Delta S \text{ in kJ/K)} \cdot \Delta G^\circ = -RT \ln K \cdot \Delta G^\circ = -nFE^\circ$$

$$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1} \cdot F = 96\,485 \text{ C/mol}$$

$$S^\circ (\text{J mol}^{-1} \text{ K}^{-1}): \text{CH}_4(\text{g}) 186.3 \cdot \text{O}_2(\text{g}) 205.2 \cdot \text{CO}_2(\text{g}) 213.8 \cdot \text{H}_2\text{O}(\text{l}) 70.0 \cdot \Delta H_f^\circ (\text{kJ/mol}): \text{CH}_4(\text{g}) -74.6 \cdot \text{CO}_2(\text{g}) -393.5 \cdot \text{H}_2\text{O}(\text{l}) -285.8$$

Show units on every quantity in every step.

A. Understanding

1. (a) What is entropy? (b) State the second law of thermodynamics. (c) Why can an endothermic process, such as ice melting at 25 °C, be spontaneous?

2. Predict the sign of ΔS : (a) $\text{H}_2\text{O}(\text{l}) \longrightarrow \text{H}_2\text{O}(\text{g})$ (b) $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{SO}_3(\text{g})$ (c) $\text{NaCl}(\text{s}) \longrightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$ (d) $\text{CaCO}_3(\text{s}) \longrightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$ (e) $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \longrightarrow 2\text{NO}(\text{g})$

3. For each reaction, say whether it is spontaneous at all temperatures, never, only at low T, or only at high T: (a) $\Delta H = -120 \text{ kJ}$, $\Delta S = +85 \text{ J/K}$ (b) $\Delta H = +45 \text{ kJ}$, $\Delta S = -30 \text{ J/K}$ (c) $\Delta H = -60 \text{ kJ}$, $\Delta S = -150 \text{ J/K}$ (d) $\Delta H = +90 \text{ kJ}$, $\Delta S = +200 \text{ J/K}$

B. Calculations

4. Calculate ΔS° for $\text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l})$ and explain its sign.

5. Calculate ΔH° and ΔG° at 298.15 K for the same reaction.

6. For melting ice, $\Delta H = +6.01 \text{ kJ/mol}$ and $\Delta S = +22.0 \text{ J mol}^{-1} \text{ K}^{-1}$. (a) At what temperature is $\Delta G = 0$? (b) Find ΔG at -10.0°C and at $+10.0^\circ \text{C}$, and explain what each result means.

7. For $\text{CaCO}_3 \longrightarrow \text{CaO} + \text{CO}_2$, $\Delta H^\circ = +179.2 \text{ kJ}$ and $\Delta S^\circ = +160.2 \text{ J/K}$. Calculate ΔG° at 1200 K. Is the decomposition spontaneous?

8. A reaction has $\Delta G^\circ = +10.0 \text{ kJ}$ at 298.15 K. Calculate K, and say whether reactants or products are favoured.

C. Challenge

9. The Daniell cell has $E^\circ = 1.10 \text{ V}$ and $n = 2$. Calculate (a) ΔG° (b) K at 298.15 K. What does the size of K tell you?