Conceptual Questions:

1. What is the second law of thermodynamics?
2. For any process, what are the four possible combinations of ΔH and ΔS? Which of these correspond to always spontaneous or always non-spontaneous reactions? Under what conditions would the last two combinations be spontaneous?
3. What is the third law of thermodynamics?
4. For a gas phase reaction, how do you determine the sign of $\Delta S°$? How about for a phase change?
5. For a liquid, would you expect ΔS_{fusion} or $\Delta S_{evaporation}$ to be larger? Why?
6. True or False: High temperatures are favorable to a reaction both kinetically and thermodynamically? Explain.

1. Calculate the standard entropy change for the following reaction at 25 °C:
   $2Al(s) + 3ZnO(s) \rightarrow Al_2O_3(s) + 3Zn\ (s)$
2. A certain reaction has $\Delta H° = -19.5$ kJ and $\Delta S° = 42.7$ J K^{-1}.
   a. Calculate $\Delta G°$ for the reaction.
   b. Is the reaction spontaneous under standard conditions?

3a. Using the data given below, calculate $\Delta G°$ for the reaction: $2SO_2\ (g) + O_2\ (g) \rightarrow 2SO_3\ (g)$
   3b. Is this reaction spontaneous as written under standard conditions?
   3c. What is the equilibrium constant *K* for this reaction?

4. Calculate $\Delta G°$ for the process: C *(diamond)* ←→ C *(graphite)*
   Is the formation of graphite from diamond favored at 25°C? If so, why is it that diamonds do not become graphite on standing?

---

5. Consider the formation of a dimeric protein: 2P → P_2. At 25°C, we have $\Delta H° = 17$ kJ/mol and $\Delta S° = 65$ J/mol*K. Is the dimerization favored at this temperature? What would be the effect of lowering the temperature?
6. The equilibrium constant K_P for the reaction below is 5.62×10^{35} at 25°C. What is $\Delta G°f$ for $COCl_2$ at 25°C? Would you predict the ΔS for this reaction to be positive or negative? ($CO\ (g) + Cl_2\ (g)$ ←→ $COCl_2\ (g)$)

Conceptual Questions:

1. What is the second law of thermodynamics?
2. For any process, what are the four possible combinations of ΔH and ΔS? Which of these correspond to always spontaneous or always non-spontaneous reactions? Under what conditions would the last two combinations be spontaneous?
3. What is the third law of thermodynamics?
4. For a gas phase reaction, how do you determine the sign of $\Delta S°$? How about for a phase change?
5. For a liquid, would you expect ΔS_{fusion} or $\Delta S_{evaporation}$ to be larger? Why?
6. True or False: High temperatures are favorable to a reaction both kinetically and thermodynamically? Explain.

1. Calculate the standard entropy change for the following reaction at 25 °C:
   $2Al(s) + 3ZnO(s) \rightarrow Al_2O_3(s) + 3Zn\ (s)$
2. A certain reaction has $\Delta H° = -19.5$ kJ and $\Delta S° = 42.7$ J K^{-1}.
   c. Calculate $\Delta G°$ for the reaction.
   d. Is the reaction spontaneous under standard conditions?

3a. Using the data given below, calculate $\Delta G°$ for the reaction: $2SO_2\ (g) + O_2\ (g) \rightarrow 2SO_3\ (g)$
   3b. Is this reaction spontaneous as written under standard conditions?
   3c. What is the equilibrium constant *K* for this reaction?

4. Calculate $\Delta G°$ for the process: C *(diamond)* ←→ C *(graphite)*
   Is the formation of graphite from diamond favored at 25°C? If so, why is it that diamonds do not become graphite on standing?

---

5. Consider the formation of a dimeric protein: 2P → P_2. At 25°C, we have $\Delta H° = 17$ kJ/mol and $\Delta S° = 65$ J/mol*K. Is the dimerization favored at this temperature? What would be the effect of lowering the temperature?
6. The equilibrium constant K_P for the reaction below is 5.62×10^{35} at 25°C. What is $\Delta G°f$ for $COCl_2$ at 25°C? Would you predict the ΔS for this reaction to be positive or negative? ($CO\ (g) + Cl_2\ (g)$ ←→ $COCl_2\ (g)$)

7. What is $\Delta G°$ for the reaction below at 25°C?

$$3Cl_2\,(g) + 2CH_4\,(g) \rightarrow CH_3Cl\,(g) + CH_2Cl_2\,(g) + 3HCl\,(g)$$

8. Consider the following reaction:

$$PCl_5(g) \leftrightarrows PCl_3(g) + Cl_2(g) \qquad \Delta G°_{rxn} = 35.4 \text{ kJ/mol}$$

Calculate ΔG at 25°C for the reaction if the partial pressures of the initial mixture are $P_{PCl5} = 0.0029$ atm, $P_{PCl3} = 0.27$ atm, and $P_{Cl2} = 0.40$ atm.

9. Which of the following reactions would be spontaneous at 25°C? If either is non-spontaneous, at what temperature would it become spontaneous?

a. $\Delta H = 10.5$ kJ/mol, $\Delta S = 30$ J/molK

b $\Delta H = 1.8$ kJ/mol, $\Delta S = -113$ J/molK

10. The equilibrium constant (K_P) for the following reaction is 4.40 at 2000K.

$$H_2\,(g) + CO_2\,(g) \leftrightarrows H_2O\,(l) + CO\,(g)$$

a. Calculate $\Delta G°$ for the reaction at 2000K

b. Calculate ΔG for the reaction when $P_{H2} = 0.78$ atm, $P_{H2O} = 0.66$ atm, and $P_{CO} = 1.20$ atm.

	$\Delta H_f°$	$S°$	$\Delta G_f°$
Al (s)		28.3 J/K•mol	
Al_2O_3 (s)		50.99 J/K•mol	
ZnO (s)		43.9 J/K•mol	
Zn (s)		41.6 J/K•mol	
SO_2 (g)			–300.4 kJ mol^{-1}
O_2 (g)			0 kJ mol^{-1}
SO_3 (g)			–370.4 kJ mol^{-1}
C (diamond)	1.90 kJ mol^{-1}	2.4 J/K•mol	
C (graphite)	0 kJ mol^{-1}	5.69 J/K•mol	
Cl_2 (g)	0 kJ mol^{-1}	223 J/K•mol	0 kJ mol^{-1}
CH_4 (g)	-74.85 kJ mol^{-1}	186.2 J/K•mol	-50.8 kJ mol^{-1}
CH_3Cl (g)	-83.68 kJ mol^{-1}	234.36 J/K•mol	---
CH_2Cl_2 (g)	-95.52 kJ mol^{-1}	270.28 J/K•mol	---
HCl (g)	-92.3 kJ mol^{-1}	187 J/K•mol	-95.27 kJ mol^{-1}

7. What is $\Delta G°$ for the reaction below at 25°C?

$$3Cl_2\,(g) + 2CH_4\,(g) \rightarrow CH_3Cl\,(g) + CH_2Cl_2\,(g) + 3HCl\,(g)$$

8. Consider the following reaction:

$$PCl_5(g) \leftrightarrows PCl_3(g) + Cl_2(g) \qquad \Delta G°_{rxn} = 35.4 \text{ kJ/mol}$$

Calculate ΔG at 25°C for the reaction if the partial pressures of the initial mixture are $P_{PCl5} = 0.0029$ atm, $P_{PCl3} = 0.27$ atm, and $P_{Cl2} = 0.40$ atm.

9. Which of the following reactions would be spontaneous at 25°C? If either is non-spontaneous, at what temperature would it become spontaneous?

a. $\Delta H = 10.5$ kJ/mol, $\Delta S = 30$ J/molK

b $\Delta H = 1.8$ kJ/mol, $\Delta S = -113$ J/molK

10. The equilibrium constant (K_P) for the following reaction is 4.40 at 2000K.

$$H_2\,(g) + CO_2\,(g) \leftrightarrows H_2O\,(l) + CO\,(g)$$

a. Calculate $\Delta G°$ for the reaction at 2000K

b. Calculate ΔG for the reaction when $P_{H2} = 0.78$ atm, $P_{H2O} = 0.66$ atm, and $P_{CO} = 1.20$ atm.

	$\Delta H_f°$	$S°$	$\Delta G_f°$
Al (s)		28.3 J/K•mol	
Al_2O_3 (s)		50.99 J/K•mol	
ZnO (s)		43.9 J/K•mol	
Zn (s)		41.6 J/K•mol	
SO_2 (g)			–300.4 kJ mol^{-1}
O_2 (g)			0 kJ mol^{-1}
SO_3 (g)			–370.4 kJ mol^{-1}
C (diamond)	1.90 kJ mol^{-1}	2.4 J/K•mol	
C (graphite)	0 kJ mol^{-1}	5.69 J/K•mol	
Cl_2 (g)	0 kJ mol^{-1}	223 J/K•mol	0 kJ mol^{-1}
CH_4 (g)	-74.85 kJ mol^{-1}	186.2 J/K•mol	-50.8 kJ mol^{-1}
CH_3Cl (g)	-83.68 kJ mol^{-1}	234.36 J/K•mol	---
CH_2Cl_2 (g)	-95.52 kJ mol^{-1}	270.28 J/K•mol	---
HCl (g)	-92.3 kJ mol^{-1}	187 J/K•mol	-95.27 kJ mol^{-1}