

- Which of the following processes are spontaneous and which are nonspontaneous?
  - spreading of the fragrance of perfume or air freshener in a room = **Spontaneous**
  - cleaning your room = **Nonspontaneous**
  - $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$  (at room temperature, 1 atm pressure) = **Nonspontaneous**
  - Building a house of cards = **Nonspontaneous**
- Predict the sign of entropy change (positive or negative) for the following processes/reactions
  - a lake freezing **negative**
  - $\text{SO}_2(\text{g}) + \text{CaO}(\text{s}) \rightarrow \text{CaSO}_3(\text{s})$  **negative**
  - $\text{NH}_3(\text{g}) + \text{HCl}(\text{g}) \rightarrow \text{NH}_4\text{Cl}(\text{s})$  **negative**
  - $4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \rightarrow 2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g})$  **Positive**
  - $\text{N}_2\text{H}_4(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{H}_2(\text{g})$  **Positive**
- Using the values for standard molar entropies ( $S^\circ$ ) from the Appendix in your text book, calculate  $\Delta S^\circ$  for the following reactions at 25°C.
  - $\text{CH}_3\text{OH}(\text{l}) \rightarrow \text{CO}(\text{g}) + 2\text{H}_2(\text{g})$  **332 J/K**
  - $\text{N}_2\text{H}_4(\text{l}) + \text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$  **133.8 J/K**
  - $\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$  **757.2 J/K**
- Consider the following reaction at constant P. Use the information here to determine the value of  $\Delta S_{\text{Surr}}$  at 355 K. Predict whether or not this reaction will be spontaneous at this temperature.
 
$$2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g}) \quad \Delta H = -114 \text{ kJ} \quad \mathbf{321 \text{ J/K}}$$
- Above what temperature does the following reaction become nonspontaneous?
 
$$2\text{H}_2\text{S}(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \quad \text{Given: } \Delta H = -1036 \text{ kJ}; \quad \Delta S = -153.2 \text{ J/K}$$

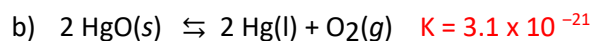
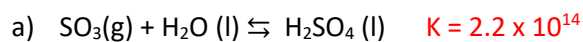
**T < 6760 K**
- What is the minimum temperature required for the spontaneous conversion of  $\text{CCl}_4(\text{l})$  to  $\text{CCl}_4(\text{g})$ ? Given:  $\Delta H^\circ_{\text{vap}}$  is 57.3 kJ/mol and  $\Delta S^\circ_{\text{vap}}$  is 164 J/(mol K) ?
 

**T > 349 K**
- Using the data in Sapling, calculate the standard Gibbs free energy change ( $\Delta G^\circ$ ) for the following reactions at 25.0°C. **In each case, indicate whether the reaction is spontaneous or not.**

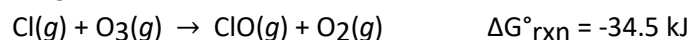
The  $\Delta G^\circ$  for  $\text{H}_2\text{SO}_4(\text{l})$  is -690 kJ/mole and is incorrect in the back of Openstax!

- $\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{SO}_4(\text{l})$  **-81.8 kJ spontaneous**
- $2\text{HgO}(\text{s}) \rightleftharpoons 2\text{Hg}(\text{l}) + \text{O}_2(\text{g})$  **+117 kJ nonspontaneous**
- $2\text{HNO}_3(\text{aq}) + \text{NO}(\text{g}) \rightleftharpoons 3\text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$  **+51 kJ nonspontaneous**

8. For each of the reactions listed in 7, calculate the value of the equilibrium constant K at 25.0°C.

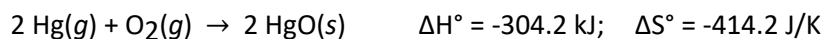


9. Use Hess's law to calculate  $\Delta G^\circ_{\text{rxn}}$  for:  $\text{ClO}(\text{g}) + \text{O}_3(\text{g}) \rightarrow \text{Cl}(\text{g}) + 2 \text{O}_2(\text{g})$   
using the following information.



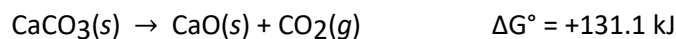
524.1 kJ

10. Estimate  $\Delta G^\circ_{\text{rxn}}$  for the following reaction at 775 K.



16.8 kJ

11. Calculate  $\Delta G_{\text{rxn}}$  at 298 K under the conditions shown below for the following reaction.



$P(\text{CO}_2) = 0.00100 \text{ atm}$

114 kJ

12. Consider the reaction  $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2 \text{NO}_2(\text{g})$

a) Using the data in your textbook, calculate the Gibbs free energy change ( $\Delta G^\circ$ ) for the reaction at 298 K.

2.8 kJ

b) Calculate the value of  $K_{\text{eq}}$  at 298 K

$K = .32$

c) Calculate  $\Delta G$  at 298 K when the partial pressures for  $\text{N}_2\text{O}_4$  and  $\text{NO}_2$  are 10.5 and 0.50 atm respectively.

-6.5 kJ

13. Consider the reaction  $\text{C}(\text{s}) + 2 \text{H}_2(\text{g}) \rightarrow \text{CH}_4(\text{g})$

a) Using the data in your textbook, calculate  $\Delta H^\circ$  and  $\Delta S^\circ$  for the reaction at 298 K.

b) Estimate  $\Delta G^\circ$  for the reaction at 400K. (is the reaction more or less spontaneous at high temperature?)

-42.3 kJ (less spontaneous at high Temp)

The following are multiple choice questions

14. Melting of a solid is an example of a process for which

- (A)  $\Delta H$ ,  $\Delta S$ , and  $\Delta G$  are positive at all temperatures. (B)  $\Delta H$  and  $\Delta S$  are positive.  
(C)  $\Delta G$  is negative at low temperatures, positive at high temperatures. (D)  $\Delta H = \Delta S$

15. For the following process:  $2\text{Cl}(g) \rightarrow \text{Cl}_2(s)$

- (A)  $\Delta H$  is + and  $\Delta S$  is + for the reaction. (B)  $\Delta H$  is – and  $\Delta S$  is – for the reaction.  
(C)  $\Delta H$  is + and  $\Delta S$  is – for the reaction. (D)  $\Delta H$  is – and  $\Delta S$  is + for the reaction.  
(E)  $\Delta G$  is + for all temperatures

16. A reaction is nonspontaneous at all temperatures if

- (A)  $\Delta H$  and  $\Delta S$  are both positive. (B)  $\Delta H$  and  $\Delta S$  are both negative.  
(C)  $\Delta H$  is positive and  $\Delta S$  is negative. (D)  $\Delta H$  is negative and  $\Delta S$  is positive.