Supplemental Activities

Module: Thermodynamics

Section: Free Energy

Gibb’s Free Energy

Activity 1

Gibb’s free energy is a thermodynamic state function. The purpose of this activity is to recall the origin of the function.

1. Both __________ __________ energy, G, and the change in entropy of the __________, $\Delta S_{universe}$, can be used to predict the spontaneity of physical or chemical change.

2. The change in the Gibb’s free energy, ΔG, is actually derived from the change in entropy of the universe. What is the equation relating the change in Gibb’s free energy for a process and the change in enthalpy and entropy for the same process? Define the variables and provide units for each.

3. What is the sign of ΔG for a spontaneous process? For a non-spontaneous process?

4. What are the four possible combinations of ΔH and ΔS and what kind of change do they lead to – always spontaneous, always non-spontaneous or temperature dependent?

Activity 2

The purpose of this activity is to further develop your understanding of Gibb’s Free Energy by investigating Gibb’s free energy of formation and Gibb’s free energy of reaction.

1. How does the change in Gibb’s free energy of formation under standard conditions, ΔG_f°, inform us about the stability of a compound?

2. Which compound would you expect to have the lowest ΔG_f° (under standard conditions) of the given pairs? Explain your choice.
    a. Br_2 (l) or Br_2 (g)?

b. O (g) or O_2 (g)?

c. Fe (s) or Fe_2O_3 (s)?

d. O_2 (g) or Al_2O_3 (s)?

3. Explain the concept of thermodynamic stability. Explain how the temperature and pressure conditions of a given environment might change the stability of a compound.

4. Corrosion is a huge obstacle in industry. One of the most common and pervasive corrosion reactions is the formation of iron rust (iron oxides). Provide a thermodynamic explanation as to why the formation of iron oxides continues to present industrial challenges.

Activity 3

The purpose of this activity is to further develop your understanding of using Hess's Law to determine the change in Gibbs free energy for a reaction, ΔG_{rxn}.

1. Calculate the ΔG_{rxn} of the following reaction using the given standard free energy of formation data:
   $6CO_2\ (g) + 6H_2O\ (l) \rightarrow C_6H_{12}O_6\ (s) + 6O_2\ (6)$
   $\Delta G_f^\circ\ _{CO_2\ (g)} = -394.36$ kJ/mol
   $\Delta G_f^\circ\ _{H_2O\ (l)} = -237$ kJ/mol
   $\Delta G_f^\circ\ _{C_6H_{12}O_6\ (s)} = -910$ kJ/mol

2. Here is a chemical reaction occurring under standard conditions:

   C (s, graphite) + ½ O_2 (g) + $2H_2$ (g) $\rightarrow$ CH_3OH (l)

   The associated thermodynamic data is:

   $S°_{\text{C (s, graphite)}} = 5.740$ J/K mol $S°_{\text{O}_2\text{ (g)}} = 205$ J/K mol $S°_{\text{H}_2\text{ (g)}} = 131$ J/K mol
   $S°_{\text{CH}_3\text{OH (l)}} = 127$ J/K mol $\Delta H_f^{\circ}{}_{\text{CH}_3\text{OH (l)}} = -239$ kJ/mol

   Calculate the ΔG_{rxn} under standard conditions from this data.

3. Is the above equation a formation equation? Explain. Look up $\Delta G_f^{\circ}{}_{\text{CH}_3\text{OH (l)}}$, and compare that tabulated value to the value you calculated here.

Predicting Spontaneity

ACTIVITY 1

The purpose of this activity is to use ΔG_{rxn} to predict change.

1. Dry ice (solid CO_2) spontaneously sublimes in room temperature. What can you conclude about the ΔH of this system: CO_2 (s) $\rightarrow$ CO_2 (g)

2. What can we conclude about the magnitude of the ΔH term in the dry ice example?

3. What can we conclude about changing the temperature and its effect on the spontaneity of this reaction? That is do you predict that decreasing the temperature will help the dry ice not sublime?

4. The equation for the formation of 2 moles of NH_3 under standard conditions is:

$$N_2\,(g) + 3H_2\,(g) \rightarrow 2NH_3\,(g)$$

The associated thermodynamic data is:

$S°_{N_2\,(g)}$ = 192 J/K mol

$S°_{H_2\,(g)}$ = 131 J/K mol

$S°_{NH_3\,(g)}$ = 193 J/K mol

ΔH_f° $_{NH_3\,(g)}$ = −46 kJ/mol

a. Given this information calculate the ΔS_{univ}. Based on the ΔS_{univ} for this example would you predict that this reaction spontaneous? Why or Why not?

b. Using the given thermodynamic data calculate ΔG_{rxn} at 298K.

c. Based on your calculated value of ΔG_{rxn} is the formation of 2 moles of NH_3 under these conditions spontaneous?

d. Is there a temperature at which point this reaction would become nonspontaneous? If so what is that temperature?

ACTIVITY 2

The purpose of this activity is to check your understanding of the temperature effects of spontaneity across change.

1. Choose the correct word to complete the statement and then give an example of that kind of reaction:
    a. An endothermic reaction for which the entropy of the system is increasing the reaction will be (choose one: always/never/sometimes) spontaneous. Give an example of such a reaction.

    b. An endothermic reaction for which the entropy of the system is decreasing the reaction will be (choose one: always/never/sometimes) spontaneous.

    c. An exothermic reaction for which the entropy of the system is increasing the reaction will be (choose one: always/never/sometimes) spontaneous. Give an example of such a reaction.

    d. An exothermic reaction for which the entropy of the system is decreasing the reaction will be (choose one: always/never/sometimes) spontaneous. Give an example of such a reaction.

2. What is the value of ΔG_{rxn} when a system is at equilibrium?

3. What is true about the forward process and the backward process of a system at equilibrium?

4. The condensation of CH_3OH gas to CH_3OH liquid is spontaneous when ΔG is negative. Using the data below, predict at what temperature is this process first spontaneous at 1 bar.

$S°$ $CH_3OH_{(g)}$ = 240 J/K mol
$S°$ $CH_3OH_{(l)}$ = 127 J/K mol
ΔH_f° $CH_3OH_{(g)}$ = −201 kJ/mol
ΔH_f° $CH_3OH_{(l)}$ = −239 kJ/mol