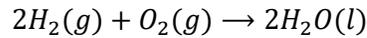


18: Entropy and Free Energy

18.2: Dispersal of Energy - Entropy

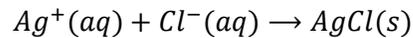
Entropy and Second Law of Thermodynamics

18.2.1. Predict the entropy change in the reaction,



- a. increase
- b. decrease
- c. same
- d. not enough information

18.2.2. Predict the entropy change in the reaction,



- a. increase
- b. decrease
- c. same
- d. not enough information

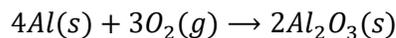
18.2.3. Which one of the following decreases the entropy of the system?

- a. dissolving NaCl in water
- b. sublimation of benzene
- c. dissolving oxygen in water
- d. boiling of alcohol

18.2.4. Which one has the highest absolute entropy at 25°C?

- a. H₂O(l)
- b. He(g)
- c. C(s)
- d. NH₃(g)

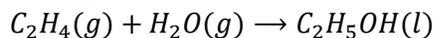
18.2.5. Calculate the change of entropy for the reaction at 25°C, where S° for Al(s), O₂(g) and Al₂O₃(s) are 28.32, 205.0 and 51.0 J/K*mol respectively.



18.6: Gibbs Free Energy

Gibbs Free Energy

18.6.1. Calculate the change of the Gibbs free energy for the reaction at 25°C, where standard free energy of formation of C₂H₄(g), H₂O(g), C₂H₅OH(l) are 68, -229, -175 kJ/mol respectively.

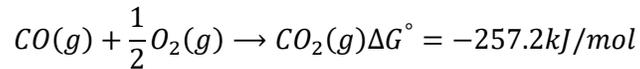
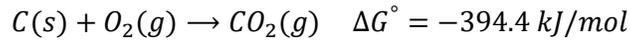


18.6.2. What is the change of entropy if S° of C₂H₄(g), H₂O(g), C₂H₅OH(l) are 219, 189, and 161 J/K*mol.

18.6.3. What is the change of enthalpy at 25°C for the same reaction?

18: Entropy and Free Energy

18.6.12. Using the information below, calculate the value of K at 25°C for the reaction of C(s) and O₂(g) to form CO.



Free Energy and Temperature

18.6.13. What is the melting point of gold, Au, at 100kPa if $\Delta H^\circ_{\text{fusion}} = 12.36 \text{ kJ/mol}$, and $\Delta S^\circ_{\text{fusion}} = 0.0092 \text{ kJ/mol}$?

18.6.14. What is the state of gold if the temperature is 1200°C?

- a. solid
- b. liquid
- c. gas
- d. a mixture of solid and liquid

18.6.15. What is the state of gold if the temperature is 900°C?

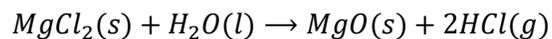
- a. solid
- b. liquid
- c. gas
- d. a mixture of liquid and gas

18.6.16. What is the $\Delta S^\circ_{\text{fusion}}$ of water if $\Delta H^\circ_{\text{fusion}} = 6.01 \text{ kJ/mol}$?

18.6.17. What is the $\Delta S^\circ_{\text{vap}}$ of water if $\Delta H^\circ_{\text{vap}} = 40.7 \text{ kJ/mol}$?

Enthalpy, Entropy, and Gibbs Free Energy

18.6.18. Use the Selected Thermodynamic Values appendix in the back of your book to answer the questions below. Your answer may differ slightly due to different tables in different texts.



- a. Find the ΔH_{rxn} for the reaction above.
- b. Find the ΔS_{rxn} for the reaction above.
- c. Find the ΔG_{rxn} for the reaction above.

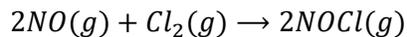
18: Entropy and Free Energy

18.6.19. Use the Selected Thermodynamic Values appendix in the back of your book to answer the questions below. Your answer may differ slightly due to different tables in different texts.



- Find the ΔH_{rxn} for the reaction above.
- Find the ΔS_{rxn} for the reaction above.
- Find the ΔG_{rxn} for the reaction above.

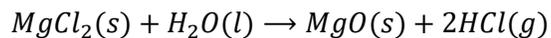
18.6.20. Use the Selected Thermodynamic Values appendix in the back of your book to answer the questions below. Your answer may differ slightly due to different tables in different texts.



- Find the ΔH_{rxn} for the reaction above.
- Find the ΔS_{rxn} for the reaction above.
- Find the ΔG_{rxn} for the reaction above.

Finding K

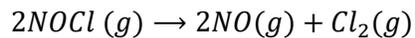
18.6.21. Find the K for the reaction at the following temperatures.



- Temperature at 25°C?
- Temperature at 20°C?
- Temperature at 100°C?

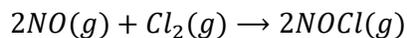
18: Entropy and Free Energy

18.6.22. Find the K for the reaction at the following temperatures.



- Temperature at 25°C?
- Temperature at 15°C?
- Temperature at 150°C?

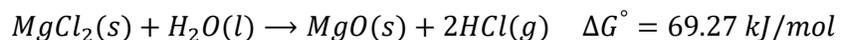
18.6.23. Find the K for the reaction at the following temperatures.



- Temperature at 25°C?
- Temperature at 10°C?
- Temperature at 200°C?

Reactant and Product Loading

Use the following reaction for questions 18.6.24-18.6.27



18.6.24. Does the reaction favor products or reactants?

- reactant
- product
- both
- none of the above

18.6.25. What is the expression for Q?

18.6.26. At what minimal pressures would the reaction proceed to the left?

18.6.27. What is the ΔG° for $P_{\text{HCl}} = 5.2 \times 10^{-4}$?

18: Entropy and Free Energy

18.6.28. What is the ΔG and does the reaction proceed towards products or reactants?

$2\text{NO(g)} +$	$\text{Cl}_2\text{(g)}$	\rightarrow	2NOCl (g)
$4.9 \cdot 10^{-6}\text{M}$	$3.1 \cdot 10^{-3}\text{M}$		$2.4 \cdot 10^{-1}\text{M}$

18.6.29. What is the ΔG and does the reaction proceed towards products or reactants?

2NOCl (g)	\rightarrow	$2\text{NO(g)} +$	$\text{Cl}_2\text{(g)}$
$3.1 \cdot 10^{-1}\text{M}$		$2.4 \cdot 10^{-6}\text{M}$	$4.9 \cdot 10^{-3}\text{M}$

General Questions

18.1. Which of the following must have a negative value for an exothermic process?

- a. enthalpy change
- b. entropy change
- c. free energy change
- d. electrode cell potential
- e. equilibrium constant

18.2. Which of the following is true when one mole of naphthalene sublimates to gas?

- 1. The entropy increases
 - 2. The entropy decreases
 - 3. The enthalpy increases
 - 4. The enthalpy decreases
- a. 1 only
 - b. 2 only
 - c. 1 and 3 only
 - d. 2 and 3 only
 - e. 1 and 4 only

18.3. The total entropy of a system and its surroundings always increases for a spontaneous process.

This is a statement of

- a. the law of constant composition
- b. the first law of thermodynamics
- c. the second law of thermodynamics
- d. the third law of thermodynamics
- e. the law of conservation of matter

18.4. Which of the following is a spontaneous process?

- 1. ice melting at 25C
 - 2. heat flowing from a hot to a cold object
 - 3. an iron tool rusting
- a. 1 only
 - b. 2 only
 - c. 3 only
 - d. 1 and 2 only
 - e. 1, 2, and 3

18: Entropy and Free Energy

18.5. The heat of vaporization of ammonia is 23.4 kJ/mol. Its boiling point is -33°C . What is the change in entropy for the vaporization of ammonia in $\text{J}/(\text{mol}\cdot\text{K})$?

18.6. At the boiling point of benzene, C_6H_6 , $\Delta H_{\text{vap}} = 30.78 \text{ kJ/mol}$, $\Delta S_{\text{vap}} = 87.15 \text{ J}/(\text{mol}\cdot\text{K})$. Determine the normal boiling temperature in degrees Celsius for C_6H_6 .

18.7. Arrange the following in order of increasing entropy:

$\text{CH}_4(\text{g})$, $\text{C}(\text{s})$, $\text{Li}(\text{s})$, $\text{Na}(\text{s})$

- | | |
|------------------------------|------------------------------|
| a. Li, C, CH_4 , Na | d. CH_4 , Li, Na, C |
| b. C, Li, Na, CH_4 | e. Na, Li, CH_4 , C |
| c. Na, Li, C, CH_4 | |

18.8. Arrange the following in order of increasing entropy, S° :

$\text{Hg}(\text{l})$, $\text{Hg}(\text{s})$, $\text{C}_6\text{H}_6(\text{l})$, $\text{CH}_3\text{OH}(\text{l})$

- | | |
|--|--|
| a. $\text{Hg}(\text{s})$, $\text{CH}_3\text{OH}(\text{l})$, $\text{C}_6\text{H}_6(\text{l})$, $\text{Hg}(\text{l})$ | d. $\text{Hg}(\text{s})$, $\text{Hg}(\text{l})$, $\text{C}_6\text{H}_6(\text{l})$, $\text{CH}_3\text{OH}(\text{l})$ |
| b. $\text{CH}_3\text{OH}(\text{l})$, $\text{Hg}(\text{s})$, $\text{Hg}(\text{l})$, $\text{C}_6\text{H}_6(\text{l})$ | e. $\text{Hg}(\text{s})$, $\text{Hg}(\text{l})$, $\text{CH}_3\text{OH}(\text{l})$, $\text{C}_6\text{H}_6(\text{l})$ |
| c. $\text{Hg}(\text{l})$, $\text{Hg}(\text{s})$, $\text{C}_6\text{H}_6(\text{l})$, $\text{CH}_3\text{OH}(\text{l})$ | |

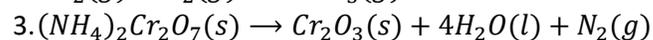
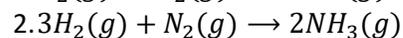
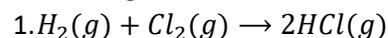
18.9. Which of the following processes would be expected to have a positive ΔS value?

- | | |
|---|--|
| a. $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$ | d. $\text{NH}_4\text{HS}(\text{s}) \rightarrow \text{NH}_3(\text{g}) + \text{H}_2\text{S}(\text{g})$ |
| b. $\text{I}_2(\text{g}) \rightarrow \text{I}_2(\text{s})$ | e. $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$ |
| c. $2\text{ClBr}(\text{g}) \rightarrow \text{Cl}_2(\text{g}) + \text{Br}_2(\text{g})$ | |

18.10. Which of the following compounds has the highest entropy in $\text{J}/(\text{mol}\cdot\text{K})$ at 298K?

- | | |
|-------------------------------------|-----------------------------------|
| a. $\text{CH}_3\text{OH}(\text{l})$ | d. $\text{H}_2\text{O}(\text{l})$ |
| b. $\text{CO}(\text{g})$ | e. $\text{CaCO}_3(\text{s})$ |
| c. $\text{SiO}_2(\text{s})$ | |

18.11. Arrange the following reactions in order of increasing $\Delta S^{\circ}_{\text{rxn}}$ values:



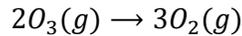
- | | |
|----------------|----------------|
| a. $1 < 3 < 2$ | d. $2 < 3 < 1$ |
| b. $1 < 2 < 3$ | e. $3 < 1 < 2$ |
| c. $2 < 1 < 3$ | |

18: Entropy and Free Energy

18.12. Which of the following processes would be expected to have a ΔS value very close to zero?

- a. $H_2O(s) \rightarrow H_2O(l)$
- b. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$
- c. $H_2O(s) \rightarrow H_2O(g)$
- d. $N_2(g) + O_2(g) \rightarrow 2NO(g)$
- e. $OF_2(g) + H_2O(g) \rightarrow O_2(g) + 2HF(g)$

18.13. Calculate ΔS° for the decomposition of ozone from oxygen.

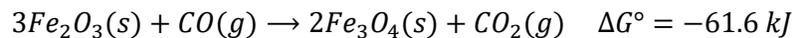
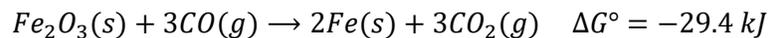


$$S^\circ = 205 \text{ J}/(\text{mol} * \text{K}) \text{ for } O_2(g), \text{ and } 239 \text{ J}/(\text{mol} * \text{K}) \text{ for } O_3(g) \text{ at } 25^\circ\text{C}$$

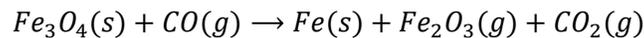
18.14. If a reaction is endothermic and nonspontaneous at 25°C , then it

- a. can never be spontaneous
- b. can become spontaneous by adding a catalyst
- c. may be spontaneous at higher temperatures
- d. may be spontaneous at lower temperatures
- e. is exothermic and spontaneous at high temperatures

18.15. Given the following



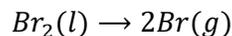
calculate ΔG° for



18.16. If a reaction is exothermic and nonspontaneous at 25°C and 1 atm of pressure, it may be

- a. spontaneous at higher temperatures
- b. spontaneous at lower temperatures
- c. endothermic at lowest temperatures
- d. endothermic at higher temperatures
- e. nonspontaneous at all temperatures

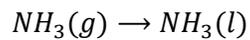
18.17. For the following process:



- a. ΔH is + and ΔS is + for the reaction
- b. ΔH is - and ΔS is - for the reaction
- c. ΔH is + and ΔS is - for the reaction
- d. ΔH is - and ΔS is + for the reaction
- e. ΔG is + for all temperatures

18: Entropy and Free Energy

18.18. The normal boiling point of ammonia is 33°C. For the process



at -40°C, the signs of ΔH , ΔS , and ΔG would be

	<u>ΔG</u>	<u>ΔH</u>	<u>ΔS</u>
a.	-	-	-
b.	-	+	+
c.	+	+	+
d.	0	+	-
e.	+	-	-

18.19. The reaction $Br_2(g) \rightarrow 2Br(l)$ is spontaneous at 1,600 °C. We can conclude that

- ΔH is + and ΔS is + for the reaction
- ΔH is - and ΔS is - for the reaction
- ΔH is + and ΔS is - for the reaction
- ΔH is - and ΔS is + for the reaction
- ΔG is + for all temperatures

18.20. For the reaction $3C(s) + 4H_2(g) \rightleftharpoons C_3H_8(g)$,

$$\Delta S^\circ = -269 \text{ J}/(\text{mol} * \text{K})$$

$$\Delta H^\circ = -103.8 \text{ kJ}/\text{mol}$$

Calculate the equilibrium constant at 25°C for the reaction above.