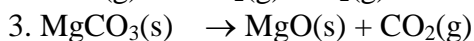
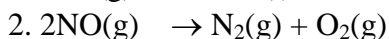
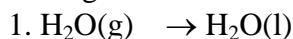


Chapter 18: Thermodynamics

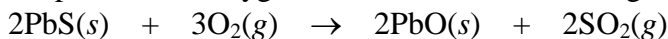
- Which of these species would you expect to have the lowest standard entropy (S°)?
A) $\text{CH}_4(\text{g})$ B) $\text{HF}(\text{g})$ C) $\text{NH}_3(\text{g})$ D) $\text{H}_2\text{O}(\text{g})$
- Which of these species would you expect to have the lowest standard entropy (S°)?
A) $\text{Br}_2(\text{l})$ B) $\text{Cl}_2(\text{g})$ C) $\text{F}_2(\text{g})$ D) $\text{H}_2(\text{g})$ E) $\text{I}_2(\text{s})$
- Which of these species has the highest entropy (S°) at 25°C ?
A) $\text{CO}(\text{g})$ B) $\text{CH}_4(\text{g})$ C) $\text{NaCl}(\text{s})$ D) $\text{H}_2\text{O}(\text{l})$ E) $\text{Fe}(\text{s})$
- Arrange the following substances in the order of increasing entropy at 25°C .
 $\text{HF}(\text{g})$, $\text{NaF}(\text{s})$, $\text{SiF}_4(\text{g})$, $\text{SiH}_4(\text{g})$, $\text{Al}(\text{s})$
lowest \rightarrow highest
A) $\text{SiF}_4(\text{g}) < \text{SiH}_4(\text{g}) < \text{NaF}(\text{s}) < \text{HF}(\text{g}) < \text{Al}(\text{s})$
B) $\text{HF}(\text{g}) < \text{Al}(\text{s}) < \text{NaF}(\text{s}) < \text{SiF}_4(\text{g}) < \text{SiH}_4(\text{g})$
C) $\text{Al}(\text{s}) < \text{NaF}(\text{s}) < \text{HF}(\text{g}) < \text{SiH}_4(\text{g}) < \text{SiF}_4(\text{g})$
D) $\text{Al}(\text{s}) < \text{HF}(\text{g}) < \text{NaF}(\text{s}) < \text{SiF}_4(\text{g}) < \text{SiH}_4(\text{g})$
E) $\text{NaF}(\text{s}) < \text{Al}(\text{s}) < \text{HF}(\text{g}) < \text{SiF}_4(\text{g}) < \text{SiH}_4(\text{g})$
- Which one of the following reactions would you expect to have highest ΔS° ?
A) $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$
B) $\text{C}_2\text{H}_2(\text{g}) + \frac{5}{2}\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$
C) $\text{C}_2\text{H}_4(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$
D) $\text{C}_2\text{H}_6(\text{g}) + \frac{7}{2}\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g})$
- Which response includes *all* of the following processes that are accompanied by an *increase* in entropy?
 - $\text{I}_2(\text{s}) \rightarrow \text{I}_2(\text{g})$
 - $2\text{I}(\text{g}) \rightarrow \text{I}_2(\text{g})$
 - $2\text{NH}_3(\text{g}) \rightarrow \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$
 - $\text{Mg}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Mg}(\text{OH})_2(\text{s})$A) 1, 2 B) 1, 3 C) 3, 4 D) 3 E) 2, 4

13. Arrange these reactions according to *increasing* ΔS .



- A) $1 < 2 < 3$ B) $2 < 3 < 1$ C) $3 < 2 < 1$ D) $2 < 1 < 3$ E) $1 < 3 < 2$

15. Sulfur can be separated from lead in the mineral galena, $\text{PbS}(\text{s})$, by “roasting” the ore in the presence of oxygen as shown in the following reaction:



Calculate ΔS° for this reaction using the thermodynamic data provided below.

	$S^\circ(\text{J/K}\cdot\text{mol})$
$\text{PbS}(\text{s})$	91.2
$\text{O}_2(\text{g})$	205.0
$\text{PbO}(\text{s})$	69.45
$\text{SO}_2(\text{g})$	248.5

- A) $-410 \text{ J/K}\cdot\text{mol}$ D) $21.8 \text{ J/K}\cdot\text{mol}$
 B) $-161.5 \text{ J/K}\cdot\text{mol}$ E) $43.5 \text{ J/K}\cdot\text{mol}$
 C) $-47.7 \text{ J/K}\cdot\text{mol}$

17. Calculate ΔS° for the reaction $\text{SO}_2(\text{s}) + \text{NO}_2(\text{g}) \rightarrow \text{SO}_3(\text{g}) + \text{NO}(\text{g})$.

	$S^\circ(\text{J/K}\cdot\text{mol})$
$\text{SO}_2(\text{g})$	248.5
$\text{SO}_3(\text{g})$	256.2
$\text{NO}(\text{g})$	210.6
$\text{NO}_2(\text{g})$	240.5

- A) $53.6 \text{ J/K}\cdot\text{mol}$ D) $474.8 \text{ J/K}\cdot\text{mol}$
 B) $-53.6 \text{ J/K}\cdot\text{mol}$ E) $-474.8 \text{ J/K}\cdot\text{mol}$
 C) $-22.2 \text{ J/K}\cdot\text{mol}$

19. HI has a normal boiling point of -35.4°C , and its ΔH_{vap} is 21.16 kJ/mol . Calculate the molar entropy of vaporization (ΔS_{vap}).

- A) $598 \text{ J/K}\cdot\text{mol}$ D) $0.068 \text{ J/K}\cdot\text{mol}$
 B) $68.6 \text{ J/K}\cdot\text{mol}$ E) $89.0 \text{ J/K}\cdot\text{mol}$
 C) $75.2 \text{ J/K}\cdot\text{mol}$

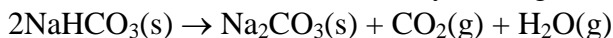
21. A negative sign for ΔG indicates that, at constant T and P,
- A) the reaction is exothermic. D) the reaction is spontaneous.
 B) the reaction is endothermic. E) ΔS must be > 0 .
 C) the reaction is fast.

23. Calculate ΔG° for the reaction $3\text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{HNO}_3(\text{l}) + \text{NO}(\text{g})$.

	ΔG°_f (kJ/mol)
$\text{H}_2\text{O}(\text{l})$	-237.2
$\text{HNO}_3(\text{l})$	-79.9
$\text{NO}(\text{g})$	86.7
$\text{NO}_2(\text{g})$	51.8

- A) 8.7 kJ/mol D) -192 kJ/mol
 B) 192 kJ/mol E) -155 kJ/mol
 C) -414 kJ/mol

25. Sodium carbonate can be made by heating sodium bicarbonate:



Given that $\Delta H^\circ = 128.9$ kJ/mol and $\Delta G^\circ = 33.1$ kJ/mol at 25°C , above what minimum temperature will the reaction become spontaneous under standard state conditions?

- A) 0.4 K B) 3.9 K C) 321 K D) 401 K E) 525 K

27. For the reaction $\text{H}_2(\text{g}) + \text{S}(\text{s}) \rightarrow \text{H}_2\text{S}(\text{g})$, $\Delta H^\circ = -20.2$ kJ/mol and $\Delta S^\circ = +43.1$ J/K mol.

Which of these statements is *true*?

- A) The reaction is only spontaneous at low temperatures.
 B) The reaction is spontaneous at all temperatures.
 C) ΔG° becomes less favorable as temperature increases.
 D) The reaction is spontaneous only at high temperatures.
 E) The reaction is at equilibrium at 25°C under standard conditions.

29. Hydrogen peroxide (H_2O_2) decomposes according to the equation



Calculate K_p for this reaction at 25°C . ($\Delta H^\circ = -98.2$ kJ/mol, $\Delta S^\circ = 70.1$ J/K mol)

- A) 1.3×10^{-21} B) 20.9 C) 3.46×10^{17} D) 7.5×10^{20} E) 8.6×10^4

31. Calculate
- K_p
- at 298 K for the reaction
- $\text{SO}_2(\text{g}) + \text{NO}_2(\text{g}) \rightarrow \text{SO}_3(\text{g}) + \text{NO}(\text{g})$
- .

	ΔG°_f
$\text{SO}_2(\text{g})$	-300.4 kJ/mol
$\text{SO}_3(\text{g})$	-370.4 kJ/mol
$\text{NO}(\text{g})$	86.7 kJ/mol
$\text{NO}_2(\text{g})$	51.8 kJ/mol

- A) 6.99×10^{-7} B) 5.71×10^{-8} C) 14.2 D) 475 E) 1.42×10^6
33. Determine the equilibrium constant K_p at 25°C for the reaction $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$
 $[\Delta G^\circ_f(\text{NH}_3(\text{g})) = -16.6 \text{ kJ/mol}]$.
 A) 1.52×10^{-6} B) 6.60×10^5 C) 8.28×10^{-2} D) 2.60 E) 13.4
35. Nitrosyl chloride (NOCl) decomposes at elevated temperatures according to the equation $2\text{NOCl}(\text{g}) \rightarrow 2\text{NO}(\text{g}) + \text{Cl}_2(\text{g})$. Calculate K_p for this reaction at 227°C. ($\Delta H^\circ = 81.2 \text{ kJ/mol}$, $\Delta S^\circ = 128 \text{ J/K}\cdot\text{mol}$)
 A) 1.59×10^{-2} B) 2.10×10^{-7} C) 62.8 D) 4.90×10^6 E) 3.20×10^9
37. For the reaction $2\text{C}(\text{graphite}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_2(\text{g})$, $\Delta G^\circ = +209.2 \text{ kJ/mol}$ at 25°C. If $P(\text{H}_2) = 100. \text{ atm}$, and $P(\text{C}_2\text{H}_2) = 0.10 \text{ atm}$, calculate ΔG for this reaction.
 A) +207.8 kJ/mol D) +17.3 kJ/mol
 B) +226.3 kJ/mol E) -16.9 kJ/mol
 C) +192.1 kJ/mol
39. K_w for the auto-ionization of water, $\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq})$, is 1.0×10^{-14} . What are the signs (+/-) of ΔS° and ΔH° for the reaction at 25°C?
 A) $\Delta S^\circ = (+)$ and $\Delta H^\circ = (+)$ C) $\Delta S^\circ = (-)$ and $\Delta H^\circ = (+)$
 B) $\Delta S^\circ = (+)$ and $\Delta H^\circ = (-)$ D) $\Delta S^\circ = (-)$ and $\Delta H^\circ = (-)$
41. The reaction rates of many spontaneous reactions are actually very slow. Which of these statements is the best explanation for this observation?
 A) K_p for the reaction is less than one.
 B) The activation energy of the reaction is large.
 C) ΔG° for the reaction is positive.
 D) Such reactions are endothermic.
 E) The entropy change is negative.

43. Calculate ΔG° for the combustion of ethanol vapor, $C_2H_5OH(g)$, at $750^\circ C$ in oxygen to form carbon dioxide and water vapor. The following data is valid at $25^\circ C$:

	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)
$C_2H_5OH(g)$	-234.8	-167.9
$O_2(g)$	0	0
$H_2O(g)$	-241.8	-228.6
$CO_2(g)$	-393.5	-394.4

- A) -1407 kJ/mol
 B) -2151 kJ/mol
 C) -1307 kJ/mol
 D) -4486 kJ/mol
 E) -1377 kJ/mol
45. Predict the normal boiling point of triethylborane ($C_6H_{15}B$) using the following data:

	ΔH_f° ($25^\circ C$)	ΔG_f° ($25^\circ C$)
$C_6H_{15}B(l)$	-194.6 kJ/mol	9.4 kJ/mol
$C_6H_{15}B(g)$	-157.7 kJ/mol	16.1 kJ/mol

- A) $92^\circ C$ B) $-21^\circ C$ C) $21^\circ C$ D) $365^\circ C$ E) $256^\circ C$
47. The standard free energy of formation of gaseous hydrogen iodide is 1.30 kJ/mol at $25^\circ C$. Find K_p for the reaction $H_2(g) + I_2(s) \rightarrow 2HI(g)$ at this temperature.
 A) 7.0 B) 7100 C) 1.0 D) 2.4 E) 2.9

49. Find the temperature at which $K_p = 42.0$ for the reaction $H_2(g) + I_2(g) \rightarrow 2HI(g)$. [Given: at $25^\circ C$, for $H_2(g)$, $\Delta H_f^\circ = 0$, $S^\circ = 131.0$ J/mol·K; for $I_2(g)$, $\Delta H_f^\circ = 62.26$ kJ/mol, $S^\circ = 260.6$ J/mol·K; for $HI(g)$, $\Delta H_f^\circ = 25.9$ kJ/mol, $S^\circ = 206.3$ J/mol·K; assume that ΔH° and ΔS° are independent of temperature.]
 A) 1040 K B) 168 K C) 539 K D) 1400 K E) 34,200 K

51. In the gas phase, formic acid forms a dimer, $2HCOOH(g) \rightarrow (HCOOH)_2(g)$. For this reaction, $\Delta H^\circ = -60.1$ kJ/mol and $\Delta G^\circ = -13.9$ kJ/mol at $25^\circ C$. Find the equilibrium constant (K_p) for this reaction at $75^\circ C$.
 A) 8960 B) 273 C) 0.120 D) 8.33 E) 1.12×10^{-4}

53. Which species will have the greatest absolute entropy at $25^\circ C$?
 A) $Ne(g)$ B) $C_2H_2(g)$ C) $H_2O(l)$ D) $C_2H_5OH(l)$ E) $C_4H_{10}(g)$