1. Which of these species has the highest entropy \( (S^\circ) \) at 25°C?
   A. CO(g)  
   B. CH₄(g)  
   C. NaCl(s)  
   D. H₂O(l)  
   E. Fe(s)

2. Arrange the following substances in the order of increasing entropy at 25°C.
   HF (g), NaF (s), SiF₄ (g), SiH₄ (g), Al (s)
   lowest \( \rightarrow \) highest
   A. SiF₄(g) < SiH₄(g) < NaF(s) < HF(g) < Al(s)
   B. HF(g) < Al(s) < NaF(s) < SiF₄(g) < SiH₄(g)
   C. Al(s) < NaF(s) < HF(g) < SiH₄(g) < SiF₄(g)
   D. Al(s) < HF(g) < NaF(s) < SiF₄(g) < SiH₄(g)
   E. NaF(s) < Al(s) < HF(g) < SiF₄(g) < SiH₄(g)

3. Which response includes all the following processes that are accompanied by an increase in entropy?
   1. \( 2\text{SO}_3(g) + \text{O}_2(g) \rightarrow 2\text{SO}_4(g) \)
   2. \( \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(s) \)
   3. \( \text{Br}_2(l) \rightarrow \text{Br}_2(g) \)
   4. \( \text{H}_2\text{O}_2(l) \rightarrow \text{H}_2\text{O}(l) + (\text{½})\text{O}_2(g) \)
   A. 1, 2, 3, 4
   B. 1, 2
   C. 2, 3, 4
   D. 3, 4
   E. 1, 4

4. Without reference to a table, arrange these reactions according to increasing \( \Delta S \).
   1. \( \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightarrow \text{CO}(g) + 3\text{H}_2(g) \)
   2. \( \text{C(s)} + \text{O}_2(g) \rightarrow \text{CO}_2(g) \)
   3. \( \text{H}_2\text{O}_2(l) \rightarrow \text{H}_2\text{O}(l) + (\text{½})\text{O}_2(g) \)
   A. 1 < 3 < 2
   B. 2 < 3 < 1
   C. 2 < 1 < 3
   D. 3 < 2 < 1
   E. 3 < 1 < 2

5. Determine \( \Delta S^\circ \) for the reaction \( \text{SO}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(l) \).
   \[ S^\circ (\text{J/K·mol}) \]
   \[
   \begin{array}{c|c}
   \text{SO}_3 & 256.2 \\
   \text{H}_2\text{O} & 69.9 \\
   \text{H}_2\text{SO}_4 & 156.9 \\
   \end{array}
   \]
   A. 169.2 J/K·mol  
   B. 1343.2 J/K·mol  
   C. −169.2 J/K·mol  
   D. −29.4 J/K·mol  
   E. 29.4 J/K·mol

6. HI has a normal boiling point of −35.4°C, and its \( \Delta H_{\text{vap}} \) is 21.16 kJ/mol. Calculate the molar entropy of vaporization \( (\Delta S_{\text{vap}}) \).
   A. 598 J/K·mol  
   B. 1343.2 J/K·mol  
   C. −169.2 J/K·mol  
   D. −29.4 J/K·mol  
   E. 89.0 J/K·mol

7. The entropy change on vaporization \( (\Delta S_{\text{vap}}) \) of a compound or element is
   A. always negative.  
   B. always positive.  
   C. sometimes positive and sometimes negative.

8. A negative sign for \( \Delta G \) indicates that, at constant \( T \) and \( P \),
   A. the reaction is exothermic.  
   B. the reaction is endothermic.  
   C. the reaction is fast.  
   D. the reaction is spontaneous.  
   E. \( \Delta S \) must be > 0.

9. Calculate \( \Delta G^\circ \) for the reaction
   \( 3\text{NO}_2(g) + \text{H}_2\text{O}(l) \rightarrow 2\text{HNO}_3(l) + \text{NO}(g) \).
   \[ \Delta G^\circ (\text{kJ/mol}) \]
   \[
   \begin{array}{c|c}
   \text{H}_2\text{O}(l) & -237.2 \\
   \text{HNO}_3(l) & -79.9 \\
   \text{NO}(g) & 86.7 \\
   \text{NO}_2(g) & 51.8 \\
   \end{array}
   \]
   A. 8.7 kJ/mol  
   B. 192 kJ/mol  
   C. −414 kJ/mol  
   D. −192 kJ/mol  
   E. −155 kJ/mol

10. The normal freezing point of ammonia is −78°C. Predict the signs of \( \Delta H \), \( \Delta S \), and \( \Delta G \) for ammonia when it freezes at −80°C and 1 atm: \( \text{NH}_3(l) \rightarrow \text{NH}_3(s) \).
    \[ \Delta H \quad \Delta S \quad \Delta G \]
    \[
    \begin{array}{c|c|c}
    \text{A.} & - & - \\
    \text{B.} & - & + \\
    \text{C.} & + & - \\
    \text{D.} & + & + \\
    \text{E.} & - & - \\
    \end{array}
    \]
11. Ozone (O₃) in the atmosphere can react with nitric oxide (NO):

\[ \text{O}_3(g) + \text{NO}(g) \rightarrow \text{NO}_2(g) + \text{O}_2(g) \]

Calculate the \( \Delta G^\circ \) for this reaction at 25°C. (\( \Delta H^\circ = -199 \) kJ/mol, \( \Delta S^\circ = -4.1 \) J/K·mol)

A. 1020 kJ/mol  
B. \(-1.22 \times 10^3 \) kJ/mol  
C. \(2.00 \times 10^3 \) kJ/mol

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

\[ 2\text{NaHCO}_3(s) \rightarrow \text{Na}_2\text{CO}_3(s) + \text{CO}_2(g) + \text{H}_2\text{O}(g) \]

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

13. Hydrogen peroxide (H₂O₂) decomposes according to the equation

\[ \text{H}_2\text{O}_2(l) \rightarrow \text{H}_2\text{O}(l) + (1/2)\text{O}_2(g) \]

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. \(1.3 \times 10^{-21}\)  
B. 20.9  
C. \(3.46 \times 10^{17}\)

14. At 1500°C the equilibrium constant for the reaction

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \]

has the value \( K_p = 1.4 \times 10^{-7} \). Calculate \( \Delta G^\circ \) for this reaction at 1500°C.

A. 105 kJ/mol  
B. 1.07 kJ/mol  
C. \(-233 \) kJ/mol

15. The equilibrium constant for the reaction

\[ \text{AgBr}(s) \rightleftharpoons \text{Ag}^+(aq) + \text{Br}^-(aq) \]

is the solubility product constant, \( K_{sp} = 7.7 \times 10^{-13} \) at 25°C. Calculate \( \Delta G \) for the reaction when \( [\text{Ag}^+] = 1.0 \times 10^{-2} \) M and \( [\text{Br}^-] = 1.0 \times 10^{-3} \) M. Is the reaction spontaneous or nonspontaneous at these concentrations?

A. \( \Delta G = 69.1 \) kJ/mol, nonspontaneous  
B. \( \Delta G = -69.1 \) kJ/mol, spontaneous  
C. \( \Delta G = 97.5 \) kJ/mol, spontaneous  
D. \( \Delta G = 40.6 \) kJ/mol, nonspontaneous  
E. \( \Delta G = -97.5 \) kJ/mol, nonspontaneous

16. \( K_w \) for the auto-ionization of water, \( \text{H}_2\text{O}(l) \rightarrow \text{H}^+(aq) + \text{OH}^-(aq) \), is \( 1.0 \times 10^{-14} \). What are the signs (+/−) of \( \Delta S^\circ \) and \( \Delta H^\circ \) for the reaction at 25°C?

A. \( \Delta S^\circ = (+) \) and \( \Delta H^\circ = (+) \)  
B. \( \Delta S^\circ = (+) \) and \( \Delta H^\circ = (-) \)  
C. \( \Delta S^\circ = (-) \) and \( \Delta H^\circ = (+) \)  
D. \( \Delta S^\circ = (-) \) and \( \Delta H^\circ = (-) \)

17. 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. \( \Delta G^\circ \) for the reaction is positive.  
D. Such reactions are endothermic.  
E. The entropy change is negative.