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$$\begin{aligned} R &= 8.314 \text{ J/(mol}\cdot\text{K)} & \Delta S^\circ &= \sum nS^\circ_{\text{(products)}} - \sum nS^\circ_{\text{(reactants)}} & \Delta S^\circ &= \sum nS^\circ_{\text{(products)}} - \sum nS^\circ_{\text{(reactants)}} & \Delta G^\circ &= \sum nG^\circ_{\text{(products)}} - \sum nG^\circ_{\text{(reactants)}} \\ \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ & \Delta G &= \Delta G^\circ + RT/\ln Q & \Delta G^\circ &= -RT/\ln K \end{aligned}$$

1. Calculate ΔS° at 25°C for the reduction of PbO(s), $2\text{PbO}(s) + \text{C}(s) \rightarrow 2\text{Pb}(s) + \text{CO}_2(g)$ given these absolute entropies:

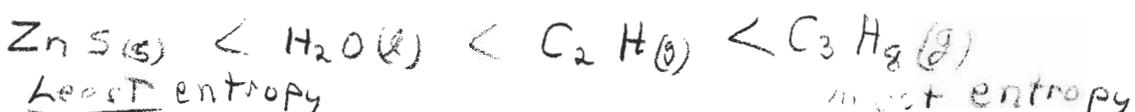
| | S° (J/K·mol) |
|---------------------|---------------------|
| PbO(s) | 69.45 |
| C(s) | 5.7 |
| Pb(s) | 64.89 |
| CO ₂ (g) | 213.6 |

$$\Delta S = \sum \Delta S_{\text{prod}} - \sum \Delta S_{\text{react}}$$

$$342.98 - 144.6$$

$\Delta S = 198.38 \text{ J/K}$

2. Arrange these compounds in order of increasing standard molar entropy at 25°C:
 $\text{C}_2\text{H}_6(\text{g})$, $\text{C}_2\text{H}_4(\text{g})$, $\text{ZnS}(\text{s})$, and $\text{H}_2\text{O}(\text{l})$.



3. 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}).

$$\text{So } \Delta H = T \Delta S$$

$$\Delta S = \frac{\Delta H}{T}$$

$$\Delta S = \frac{21.16 \times 10^3 \text{ J/mol}}{237 \text{ K}} = \underline{\underline{89.3 \text{ J/mol} \cdot \text{K}}}$$

4. Which one of the following reactions would you expect to have highest ΔS° ?

- A) $\text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)$ $3 \rightarrow 3$
 B) $\text{C}_2\text{H}_2(g) + \frac{5}{2}\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + \text{H}_2\text{O}(g)$ $3, \cancel{5} \rightarrow 2$
 C) $\text{C}_2\text{H}_4(g) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 2\text{H}_2\text{O}(g)$ $4 \rightarrow 4$
 D) $\text{C}_2\text{H}_6(g) + \frac{7}{2}\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(g)$ $4, 3 - 5 \leftarrow \text{New! } g \neq s$

5. Calculate ΔS° at 25°C for the reduction of PbO(s), $2\text{PbO}(s) + \text{C}(s) \rightarrow 2\text{Pb}(s) + \text{CO}_2(g)$ given these absolute entropies:

| | <u>S° (J/K·mol)</u> |
|---------------------|---------------------|
| PbO(s) | 69.45 |
| C(s) | 5.7 |
| Pb(s) | 64.89 |
| CO ₂ (g) | 213.6 |

S A m e a : # 1

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

$$\Delta G^\circ_f \text{ (kJ/mol)} \quad \Delta G = \sum \Delta G_{\text{Prod.}} - \sum \Delta G_{\text{React}}$$

| | |
|----------------------|--------|
| H ₂ O(l) | -237.2 |
| HNO ₃ (l) | -79.9 |
| NO(g) | 86.7 |
| NO ₂ (g) | 51.8 |

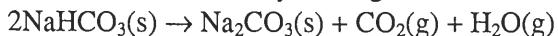
$$- 73.1 - (-81.8)$$

$$\boxed{\Delta G = 8.7 \text{ kJ}}$$

more on back

Key

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



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

$$\Delta G = \Delta H - T\Delta S$$

$$33.1 = 128.9 - 298\Delta S$$

$$\Delta S = 0.322 \text{ J/K}\cdot\text{mol}$$

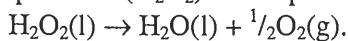
$$\Delta G = \Delta H - T\Delta S$$

$$0 = 128.9 - T(0.322)$$

$$T = 401 \text{ K}$$

or 128°C

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



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

$$\Delta G^\circ = -98.2 - 298(0.0701)$$

$$\Delta G^\circ = -119 \text{ kJ}$$

$$\Delta G^\circ = -RT \ln K$$

$$\ln K = \frac{\Delta G^\circ}{RT} = \frac{-119 \times 10^3}{8.314 \times 298}$$

$$\ln K = 48.007 \quad (K = 7.5 \times 10^{20})$$

8. At 1500°C the equilibrium constant for the reaction $\text{CO(g)} + 2\text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{OH(g)}$ has the value $K_p = 1.4 \times 10^{-7}$.

Calculate ΔG° for this reaction at 1500°C .

$$\Delta G^\circ = -RT \ln K$$

$$\Delta G^\circ = (-8.314)(1733) \ln 1.4 \times 10^{-7} = 232032 \text{ J}$$

$$233 \text{ kJ}$$

9. Assuming ΔS° and ΔH° do not vary with temperature, at what temperature will the reaction shown below become spontaneous?



$$\Delta G = \Delta H - T\Delta S$$

$$0 = 131.3 - T(0.1336)$$

$$T = 983 \text{ K}$$

$$T > 983 \text{ K}$$

$$\text{or } > 710^\circ\text{C}$$

10. For the reaction $\text{H}_2\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O(g)} + \frac{1}{2}\text{O}_2(\text{g})$, $\Delta H^\circ = -106 \text{ kJ/mol}$ and $\Delta S^\circ = 58 \text{ J/K}\cdot\text{mol}$ at 25°C . Calculate ΔG° for this reaction at this temperature.

$$\Delta G = \Delta H - T\Delta S$$

$$= -106 - 298(0.058)$$

$$= -123 \text{ kJ}$$