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

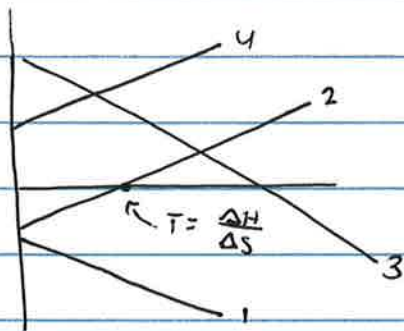
$$(-) = (-) - (+)(+)$$

$$-/+ = (-) - (+)(-)$$

$$-/+ = (+) - (+)(+)$$

$$(+) = (+) - (+)(-)$$

exothermic, entropy favored, spontaneous
 exothermic, entropy not favored, spontaneous at low T
 endothermic, entropy favored, spontaneous at high T
 endothermic, entropy not favored, not spontaneous



$$\Delta G = \Delta H - T\Delta S \quad \text{can be any conditions}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad \text{std. conditions: 1 atm, 1 M, 25}^\circ\text{C (298 K)}$$

* ΔS and ΔH are mostly temperature independent, so you can use ΔH° and ΔS° in both equations

$$\Delta G = \Delta G^\circ + RTQ \quad \text{for initial conditions}$$

$$\text{*at equilibrium } \Delta G = 0, \Delta G^\circ = -RT \ln K$$

17.109

(urea)



spontaneous

$\Delta G = -13.8 \text{ kJ}$
 • entropy not favored

*since $\Delta G < 0$ and the reaction is entropy not favored, ΔH must be positive

• the reaction is spontaneous at low T, non-spontaneous at high T
 • Calc ΔG if $P_{\text{NH}_3} = 10 \text{ atm}$, $P_{\text{CO}_2} = 10 \text{ atm}$, $[\text{urea}] = 1.0 \text{ M}$ at 25°C

$$\Delta G = \Delta G^\circ + RT \ln Q \quad Q = \frac{[\text{urea}]}{(P_{\text{NH}_3})^2 P_{\text{CO}_2}} = \frac{1.0 \text{ M}}{(10 \text{ atm})^2 (10 \text{ atm})}$$

$$\Delta G = -13.8 \text{ kJ} + (0.008314 \frac{\text{kJ}}{\text{mol}\cdot\text{K}})(298 \text{ K}) \ln\left(\frac{1}{10^3}\right)$$

$$\Delta G = -13.8 \text{ kJ} - 17.1 \text{ kJ}$$

$$\Delta G = -30.9 \text{ kJ} \quad \text{spontaneous}$$

b) What is ΔG if $P_{NH_3} = 0.10 \text{ atm}$ $P_{CO_2} = 0.10 \text{ atm}$ $[urea]_T = 1.0 \text{ M}$

$$\Delta G = \Delta G^\circ + RT \ln Q$$

$$\Delta G = -13.8 \text{ kJ} + \left(0.008314 \frac{\text{kJ}}{\text{K} \cdot \text{mol}} \right) (298 \text{ K}) \left(\frac{1.0 \text{ M}}{(0.10)^2 (0.10)} \right)$$

$$\Delta G = -13.8 \text{ kJ} + 17.1 \text{ kJ}$$

$$\boxed{\Delta G = +3.3 \text{ kJ}} \quad \text{non spontaneous}$$

c) What is K ?

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

$$-13.8 \text{ kJ} = - \left(0.008314 \frac{\text{kJ}}{\text{K} \cdot \text{mol}} \right) (298 \text{ K}) \ln K$$

$$K = +262$$

* since it's spontaneous K will be bigger than 1

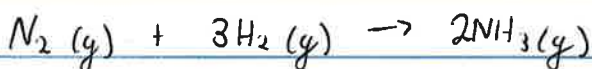
Asprin is a weak acid, $K_a = 3.0 \times 10^{-4}$. Calculate ΔG°

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

$$\Delta G^\circ = - \left(0.008314 \frac{\text{kJ}}{\text{K}} \right) (298 \text{ K}) \ln (3.0 \times 10^{-4})$$

$$\boxed{\Delta G^\circ = +20.1 \text{ kJ}} \quad \text{nonspontaneous (doesn't happen much)}$$

Haber Process



• Is it spontaneous at 350K?

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

$$\Delta G = -92.2 \text{ kJ} - (350 \text{ K}) \left(-0.199 \frac{\text{kJ}}{\text{K}} \right)$$

$$\Delta G = -23 \text{ kJ} \quad \text{spontaneous}$$

$$\Delta G^\circ = -33.0 \text{ kJ}$$

$$\Delta H^\circ = -92.2 \text{ kJ}$$

$$\Delta S = -199 \frac{\text{J}}{\text{K}} \quad \text{entropy not favored!}$$

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

$$-33.0 \text{ kJ} = -92.2 \text{ kJ} - (298 \text{ K})(\Delta S)$$

$$\Delta S^\circ = 0.199 \text{ kJ/K}$$

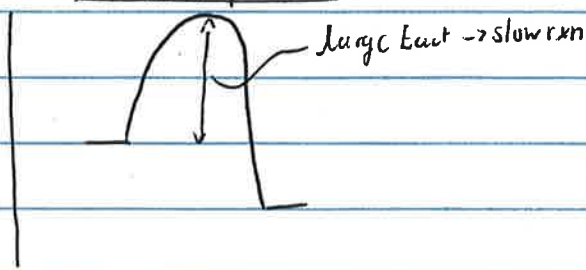
• Calc T at which $\Delta G = 0$

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

$$T = \frac{-92.2 \text{ kJ}}{-0.199 \text{ kJ/K}}$$

$$T = 463 \text{ K}$$

Reaction profile



Progress

Hess's law

