

Name: George Paxos

**Important:** This exam must be turned in handwritten. It can be on lined paper.

**It must be turned in as a single PDF. Image files for each page will not be accepted.**

You can download Adobe Scan on your phone to make the PDF.

<https://acrobat.adobe.com/us/en/mobile/scanner-app.html>

Who did you work with?

- a. Valeria van Merkerk
- b. Gabriela Inojosa Tenorio
- c. Ashley Faro
- d.

Who else did you ask for help?

George Pappas Exam 2

1a  $\Delta G_{rxn}^{\circ} = [(-394 \frac{kJ}{mol}) + (-133 \frac{kJ}{mol})] - [463 \frac{kJ}{mol}] = -84 \text{ kJ/mol}$

$\Delta H_{rxn}^{\circ} = [(-394 \frac{kJ}{mol}) + (-166 \text{ kJ/mol})] - [-584 \frac{kJ}{mol}] = 24 \text{ kJ/mol}$

Standard state conditions indicates 298 K

$$K_p = e^{\left( \frac{-84 \frac{kJ}{mol}}{(8.314 \frac{J}{mol \cdot K})(298)} \right)}$$

$$K_p = 1.65 \text{ E } 11$$

The reaction is spontaneous because  $\Delta G_{rxn}^{\circ}$  is negative.

1b  $\Delta G_{rxn}^{\circ} = -84 \text{ kJ/mol}$   
 $\Delta H_{rxn}^{\circ} = 24 \text{ kJ/mol}$

$$\ln \left( \frac{K_2}{K_1} \right) = - \frac{\Delta H_{rxn}^{\circ}}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)$$

$$\ln \left( \frac{K_2}{1.65 \text{ E } 11} \right) = \left( \frac{-24 \text{ kJ/mol}}{8.314 \text{ J/mol} \cdot \text{K}} \right) \left( \frac{1}{80} - \frac{1}{298} \right)$$

$$K_2 = .567$$

1c At lower temperatures the reaction favors reactants.

2a  $dA = -SdT - PdV$

$$\frac{\partial}{\partial T} \left( \frac{\partial A}{\partial V} \right)_T = -P \quad \frac{\partial}{\partial V} \left( \frac{\partial A}{\partial T} \right)_V = -S$$

$$\frac{\partial^2 A}{\partial T \partial V} = \left( \frac{-\partial P}{\partial T} \right)_V \quad \left( \frac{\partial^2 A}{\partial V \partial T} \right) = \left( \frac{-\partial S}{\partial V} \right)_T$$

$$\left( \frac{\partial P}{\partial T} \right)_V = \frac{\beta}{K} \quad \left( \frac{\partial P}{\partial T} \right)_V = \left( \frac{\partial S}{\partial V} \right)_T$$

$$S_m = \frac{S}{n}$$

$$\frac{1}{n} \left( \frac{\beta}{K} = \left( \frac{\partial S}{\partial V} \right)_T \right)$$

$$\frac{\beta}{nK} = \left( \frac{\partial S_m}{\partial V} \right)_T$$

2b as Volume increases, molar entropy increases

2c  $dG = SdT + VdP + \sum \mu_i dn_i$

$$\frac{\partial}{\partial n_i} \left( \frac{\partial G}{\partial P} \right)_{T, n_{i \neq j}} = V \quad \frac{\partial}{\partial P} \left( \frac{\partial G}{\partial n_i} \right)_{T, P, n_{i \neq j}} = \mu_i$$

$$\frac{\partial^2 G}{\partial n_i \partial P} = \left( \frac{\partial V}{\partial n_i} \right)_{T, P, n_{i \neq j}}$$

$$\frac{\partial^2 G}{\partial P \partial n_i} = \left( \frac{\partial \mu_i}{\partial P} \right)_{T, n_{i \neq j}}$$

$$\left( \frac{\partial V}{\partial n_i} \right)_{T, P, n_{i \neq j}} = \left( \frac{\partial \mu_i}{\partial P} \right)_{T, n_{i \neq j}}$$



$$dG = -SdT + VdP + \mu_{Cl_2} dn_{Cl_2} + \mu_{CO} dn_{CO} + \mu_{CoCl_2} dn_{CoCl_2}$$

$$\left( \frac{\partial G}{\partial P} \right)_{T, P, n_{Cl_2}, n_{CO}} = V$$

$$\left( \frac{\partial G}{\partial n_{CoCl_2}} \right)_{T, P, n_{Cl_2}, n_{CO}} = \mu_{CoCl_2}$$

$$\frac{\partial^2 G}{\partial n_{CoCl_2} \partial P} = \left( \frac{\partial V}{\partial n_{CoCl_2}} \right)$$

$$\left( \frac{\partial^2 G}{\partial P \partial n_{CoCl_2}} \right) = \left( \frac{\partial \mu_{CoCl_2}}{\partial P} \right)$$

$$\left( \frac{\partial V}{\partial n_{CoCl_2}} \right)_{T, P, n_{Cl_2}, n_{CO}} = \left( \frac{\partial \mu_{CoCl_2}}{\partial P} \right)_{T, n_{Cl_2}, n_{CO}}$$

As pressure increases, chemical potential increases

$$\left( \frac{\partial \mu_{CoCl_2}}{\partial P} \right)_{T, n_{Cl_2}, n_{CO}} = \left( \frac{\partial V}{\partial n_{CoCl_2}} \right)_{T, P, n_{Cl_2}, n_{CO}}$$

$$\int_{P_0}^P \partial \mu_{CoCl_2} = \int_{P_0}^P \left( \frac{\partial V}{\partial n_{CoCl_2}} \right) dP$$

$$V = \frac{nRT}{P}$$

$$dV = \frac{dnRT}{P}$$

$$\left( \frac{\partial V}{\partial n} \right) = \frac{RT}{P}$$

$$\int_{P_0}^P \partial \mu_{CoCl_2} = RT \int_{P_0}^P \frac{1}{P} dP$$

$$\mu_{CoCl_2}(P) - \mu_{CoCl_2}^0(P_0) = RT \int_{P_0}^P \frac{1}{P} dP$$

$$\boxed{\mu_{CoCl_2}(P) = \mu_{CoCl_2}^0 + RT \ln \frac{P}{P_0}}$$

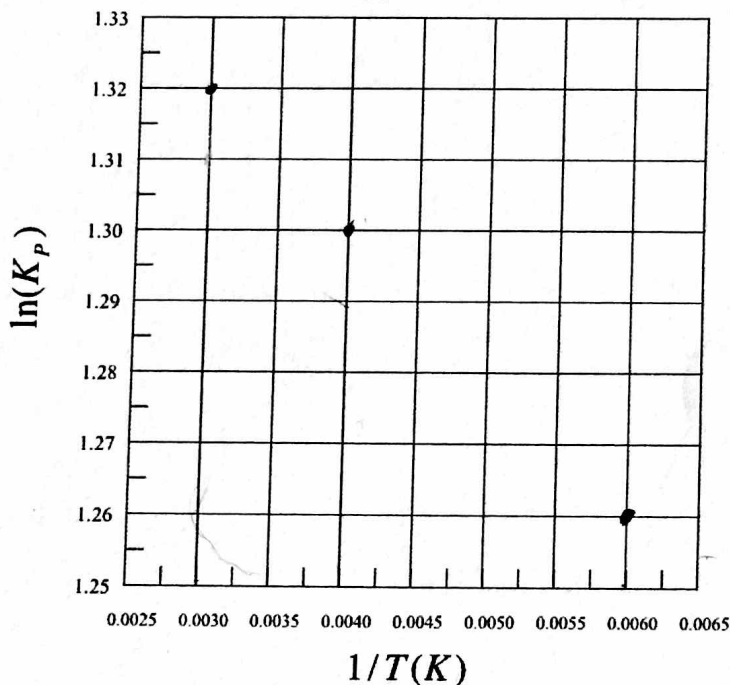
final Answer

Exam #2: 4-2-2020: Please show all work for credit, Don't Panic

3. The following thermodynamic data was measured for a chemical reaction:

T (K)	K <sub>P</sub>
167	3.53
250	3.67
333	3.74

a. Plot the data on the following plot



b. Calculate  $\Delta G_r^\circ$  for this reaction. Is this reaction spontaneous? Justify your answer.

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

$$-1.76 \frac{\text{KJ}}{\text{mol}} = -(0.008314 \frac{\text{KJ}}{\text{mol K}})(167 \text{ K}) \ln(3.53) \quad \text{Slope} = \frac{1.3 - 1.32}{0.004 - 0.003} = -20$$

$$-3.13 \frac{\text{KJ}}{\text{mol}} = -(0.008314 \frac{\text{KJ}}{\text{mol K}})(250 \text{ K}) \ln(3.67) \quad 1.32 = -20(0.003) + b$$

$$-3.54 \frac{\text{KJ}}{\text{mol}} = -(0.008314 \frac{\text{KJ}}{\text{mol K}})(333 \text{ K}) \ln(3.74) \quad b = 1.38$$

$$\text{Avg. } \Delta G_r^\circ = -2.81 \text{ KJ/mol}$$

$$\Delta H = \frac{20 \times 8314 \frac{\text{J}}{\text{mol K}}}{1000} \cdot K = 1.6628 \frac{\text{KJ}}{\text{mol}}$$

$$\Delta S = (138)(8314 \frac{\text{J}}{\text{mol K}}) = 11.425 \frac{\text{J}}{\text{mol K}}$$

c. Is this reaction enthalpically or entropically driven. Justify your answer.

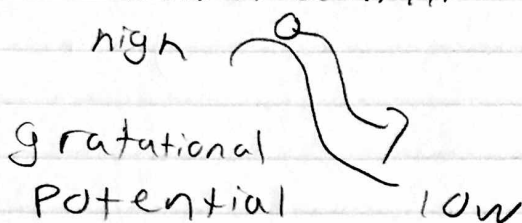
The reaction is spontaneous,  $\Delta H$  is positive and  $\Delta S$  is positive. The reaction is entropically driven because the positive entropy is able to overcome the unfavorable positive enthalpy.

Short Answers:

4. The 2<sup>nd</sup> Law of Thermodynamics states that it is impossible to convert 100% energy into work without some loss to heat. Efficiency is always less than 100%.
5. The third law of Thermodynamics states that the entropy of a pure, perfectly crystalline substance is zero at zero Kelvin.  
  
Entropy is an ever increasing value in the universe and there is a reference point where entropy is zero. Neither of these properties are seen in energy or enthalpy.
6. A perpetual motion machine would violate the 1<sup>st</sup> and 2<sup>nd</sup> law of thermodynamics. It would violate the 1<sup>st</sup> law of thermodynamics because a finite amount of energy can not become an infinite amount of energy. The second law of thermodynamics is also violated because a machine can not run forever on a finite amount of energy because the efficiency of any process is always less than 100%.
7. Helmholtz energy assumes  $DP$  and  $DT$  are zero. Gibbs energy assumes  $DP$  and  $DT$  are zero. Creating a constant volume system as a bench top chemist is more difficult than a constant pressure system so Gibbs is more useful.

$$8. \left( \frac{\partial G}{\partial n_i} \right)_{P, T, n_{j \neq i}} = \mu_i$$

A potential is a natural change in direction from high to low. So for  $n_i > n_j$  it is favorable for  $n_i$  to become  $n_j$  in the same way a ball rolls down a hill.



$$9. \Delta G_{\text{mixing}} = nRT \sum_i x_i \ln x_i$$

$$x_i < 1$$

$$\text{so } \ln x_i < 0$$

$\Delta G_{\text{mixing}}$  is always spontaneous, for an ideal gas.

$$10. K_p = e^{\left( \frac{-\Delta G_{\text{rxn}}^0}{RT} \right)} \quad (1)$$

For an ideal gas at equilibrium  $\Delta G_{\text{rxn}}^0 > 0$

As we increase the value of  $\Delta G_{\text{rxn}}^0$ ,  $K_p$  decreases, so reactants are favored.

My favorite equation from this semester is  $dU = \delta q + \delta w$  because something incredibly simple can be used to define entropy and create the 2<sup>nd</sup> law of thermodynamics using the Carnot Cycle.