

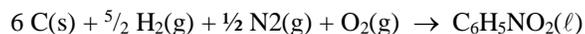
(Note: Exam 1 is Friday, October 6th. It will cover material from Chapters 12, 13, and 14).

WORKSHEETS ARE DUE AT THE BEGINNING OF CLASS ON THE DATE GIVEN ON THE WORKSHEET. LATE WORKSHEETS WILL NOT BE ACCEPTED.

NAME _____ Panther ID _____

For problems involving calculations you must show your work for credit.

1) Give the correctly balanced formation reaction for nitrobenzene ($C_6H_5NO_2(\ell)$).

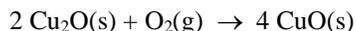


Answer is found using the definition of the formation reaction – production of one mole of a single substance out of elements in their standard (thermodynamically most stable) state.

2) Thermodynamic data for several pure chemical substances are given below (at $T = 298.0$ K).

Substance	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
CuO(s)	- 157.3	- 129.6	42.63
Cu ₂ O(s)	- 168.6	- 146.0	93.14
O ₂ (g)	0.0	0.0	205.14

a) Using the above information, find the values for ΔH_{rxn}° , ΔG_{rxn}° , and ΔS_{rxn}° for the following reaction, at $T = 298$. K.



$$\begin{aligned} \Delta H_{rxn}^\circ &= [4 \Delta H_f^\circ(CuO(s))] - [2 \Delta H_f^\circ(Cu_2O(s)) + \Delta H_f^\circ(O_2(g))] \\ &= [4 (- 157.3)] - [2 (- 168.6) + 0.] = - 292.0 \text{ kJ/mol} \end{aligned}$$

$$\begin{aligned} \Delta G_{rxn}^\circ &= [4 \Delta G_f^\circ(CuO(s))] - [2 \Delta G_f^\circ(Cu_2O(s)) + \Delta G_f^\circ(O_2(g))] \\ &= [4 (- 129.6)] - [2 (- 146.0) + 0.] = - 226.4 \text{ kJ/mol} \end{aligned}$$

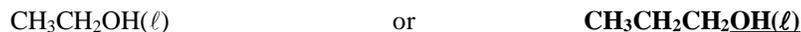
$$\begin{aligned} \Delta S_{rxn}^\circ &= [4 S^\circ(CuO(s))] - [2 S^\circ(Cu_2O(s)) + S^\circ(O_2(g))] \\ &= [4 (42.63)] - [2 (93.14) + 205.14] = - 220.90 \text{ J/mol}\cdot\text{K} \end{aligned}$$

b) Using your answers from part a, show that (to within roundoff error) $\Delta G_{rxn}^\circ = \Delta H_{rxn}^\circ - T\Delta S_{rxn}^\circ$.

$$\Delta G_{rxn}^\circ = \Delta H_{rxn}^\circ - T\Delta S_{rxn}^\circ = - 292.0 \text{ kJ/mol} - (298. \text{ K})(-0.2209 \text{ J/mol}\cdot\text{K}) = - 226.2 \text{ kJ/mol}$$

That is the same value (within roundoff error) as found directly using the data on free energies of formation in part a of the problem.

3) For each of the following pairs of substances circle the one expected to have the larger value for absolute entropy at $p = 1.00 \text{ atm}$ and $T = 25.0 \text{ }^\circ\text{C}$.



Molecules in the same family and phase, and so the larger molecule has the larger absolute entropy.



Same molecule, so when in the gas phase it has a larger absolute entropy than when in the liquid phase.



Both of these are diatomic molecules in the gas phase, but NO is made up of two different elements, while N_2 is made up of a single element. So NO is more disordered (higher absolute entropy) than N_2 .

4) For a particular chemical reaction $\Delta H^\circ_{\text{rxn}} > 0$ and $\Delta S^\circ_{\text{rxn}} > 0$. Assuming that both $\Delta H^\circ_{\text{rxn}}$ and $\Delta S^\circ_{\text{rxn}}$ are approximately independent of temperature, which of the following is expected to be true?

- a) The reaction is always spontaneous
- b) The reaction is never spontaneous
- c) The reaction is spontaneous at low temperatures but not at high temperatures
- d) The reaction is spontaneous at high temperatures but not at low temperatures
- e) Any of the above might be true for the reaction

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Since $\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$, then at low temperatures $\Delta G^\circ_{\text{rxn}} \cong \Delta H^\circ_{\text{rxn}}$. Since $\Delta H^\circ_{\text{rxn}}$ is positive, then $\Delta G^\circ_{\text{rxn}}$ will also be positive at low temperatures.

Since $\Delta S^\circ_{\text{rxn}} > 0$, the second term will be negative. As T gets larger and larger, the second term becomes larger and negative. Since we assume $\Delta H^\circ_{\text{rxn}}$ is constant, the second term will eventually become larger in magnitude than the first term. At that point $\Delta G^\circ_{\text{rxn}}$ will become negative, and the reaction will become spontaneous. The reaction therefore is spontaneous at high temperatures.