Midterm 2 Problems

February 21, 2022

1. (5 pts) **Van't Hoff Equation** Nitrosyl chloride ClNO(g) decomposes into NO(g) and Cl_2(g). The unbalanced chemical equation is

$$\mathrm{ClNO\,(g)} \rightleftharpoons \mathrm{NO\,(g)} + \mathrm{Cl_2\,(g)}$$

Using the Van't Hoff equation

$$\ln K = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \tag{1}$$

and the gas phase thermochemistry data, determine the following. Report all results to 3 significant figures.

(a) Balance the chemical equation.

(b) At what temperature is the equilibrium constant K greater than 1?

(c) At 25°C, suppose the reaction is at equilibrium. The temperature is increased. Describe the change in K in terms of the thermodynamic quantities. *Hint:* Create a plot to illustrate the process.

Table 1: Reported ΔH° (kJ/mol) and ΔS° (J/(mol K))

	ΔH°	ΔS°
NO	90.29	210.76
ClNO	51.71	261.68
Cl_2	0.00	223.08

2. (6 pts) **Mixing of Ideal Gas** Assume ideal gas conditions. At 25°C, nitrogen dioxide $NO_2(g)$ and dinitrogen tetraoxide $N_2O_4(g)$ are separated into equal volumes V, see Fig. 1. The initial pressures of the $NO_2(g)$ and $N_2O_4(g)$ are both at 1.25 atm. The valve is then opened allowing the gases to mix. Report all results to 2 significant figures.

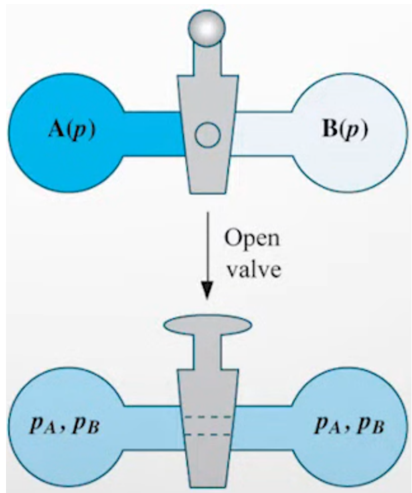

Figure 1: Illustration of gases A and B separated into equal volumes.

(a) Determine the free energy of mixing ΔG_{mix} and entropy of mixing ΔS_{mix}.

(b) $N_2O_4(g)$ is in equilibrium with $NO_2(g)$. Write the balanced chemical equation including states.

(c) At 25°C, the equilibrium constant K is 0.1481 for the $N_2O_4(g)$ decomposition. When the gases mix and allow to equilibrate, describe the "driving force" in terms of the thermodynamic quantities.

3. (4 pts) **Properties of Equilibrium Constants** Determine K_c at 25°C for the reaction,

$$N_2(g) + O_2(g) + Cl_2(g) \rightleftharpoons 2\,NOCl(g),$$

given the following data set at 25°C. Report result to 2 significant figures.

$$N_2(g) + 2\,O_2(g) \rightleftharpoons 2\,NO_2(g) \quad K_p = 1.0 \times 10^{-18}$$
$$2\,NOCl(g) + O_2(g) \rightleftharpoons 2\,NO_2Cl(g) \quad K_p = 1.21 \times 10^{4}$$
$$2\,NO_2(g) + Cl_2(g) \rightleftharpoons 2\,NO_2Cl(g) \quad K_p = 9.0 \times 10^{-2}$$