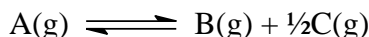


Equilibrium Problems (no calculator)

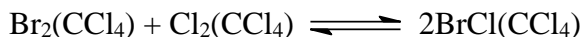
You can do these problems with or without a calculator. The answers here were calculated without a calculator.

1. For the equilibrium



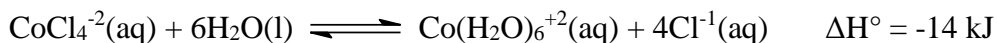
$$K_c = 4.0 \times 10^{-13} \text{ at } 27^\circ\text{C}.$$

- a) Evaluate K_P at 27°C . [**2.0×10^{-12}**]
- b) If a flask initially containing only 1.00 bar of A(g) is allowed to come to equilibrium, what will be the equilibrium pressure of each species?
[**$P_A = 1 \text{ bar}$; $P_B = 2.0 \times 10^{-8} \text{ bar}$; $P_C = 1.0 \times 10^{-8} \text{ bar}$**]
2. Bromine and chlorine both dissolve in carbon tetrachloride, whereupon they react (slowly) to form BrCl:



Under equilibrium conditions at some temperature, $[\text{Br}_2] = [\text{Cl}_2] = 0.50 \text{ M}$, and $[\text{BrCl}] = 0.10 \text{ M}$.

- a) Evaluate the equilibrium constant for this reaction at 25°C . [**0.040 or 1/25**]
- b) If 0.22 moles of BrCl were added to the equilibrium mixture you found in (a), what would be the new equilibrium concentrations of all species present? Assume 1 L of solution. ([**Br_2**] = [**Cl_2**] = **0.60 M**; [**BrCl**] = **0.12 M**)
3. Predict the effect each of the following would have on the reaction (initially at equilibrium):



Indicate your choice by writing shift **R**ight, shift **L**eft, or **N**o change:

- a) Adding HCl gas _____
- b) Heating the reaction _____
- c) Adding AgNO_3 (AgCl is insoluble) _____
- d) Adding water _____

[**L L R R**]

4. The ionization of water is an equilibrium process for which $K_c = 1.0 \times 10^{-14}$ at 25°C :

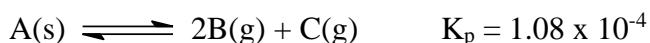


Should K_w be larger or smaller at 75°C than at 25°C ? How do you know?

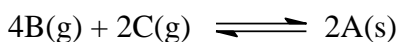
Determine the approximate K_w of water at 75°C . [**about 2×10^{-13}**]

5. The normal boiling point of a liquid is 67°C and its enthalpy of vaporization is 34 kJ/mol . What is its vapour pressure (in atmospheres) at 27°C ? [**about 0.2**]

6. Solid compound A decomposes according to the endothermic reaction:

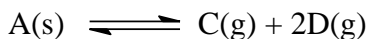


- a) If 50.0 mmol of $\text{A}(\text{s})$ is placed in a 6.10-L sealed, evacuated flask at 25°C , calculate the total pressure in the flask at equilibrium. (**$9.0 \times 10^{-2} \text{ bar}$**)
- b) How many millimoles of $\text{A}(\text{s})$ will be left at equilibrium in the experiment described in part (a)? (**42.5**)
- c) If some $\text{A}(\text{s})$ is placed in a 6.10-L evacuated flask at 25°C and some $\text{C}(\text{g})$ added so that the partial pressure of $\text{C}(\text{g})$ at equilibrium is 1.00 bar , calculate the equilibrium partial pressure of $\text{B}(\text{g})$ in the system. (**about $1 \times 10^{-2} \text{ bar}$**)
- d) What is the value of K_p for the equilibrium:



(**about 9×10^7**)

- e) If the equilibrium $\text{B}(\text{g}) \rightleftharpoons \text{D}(\text{g})$ has equilibrium constant $K_p = 5.0 \times 10^{-3}$, determine the equilibrium constant for the reaction



(**about 3×10^{-9}**)

7. The fastest growing use of methanol (CH₃OH) is to make the octane enhancer methyl tert-butyl ether. Today all methanol is produced (as a gas) by the reaction of carbon monoxide and hydrogen. The value of K_p for this reaction is (about) 2.0 x 10⁻⁴ at 327.°C.
- Write the equilibrium reaction for the production of methanol.
(2H₂(g) + CO(g) \rightleftharpoons CH₃OH(g))
 - What is the value of K_c at 327.°C? **(about 0.5)**
 - In which direction will this reaction shift if the temperature is raised, given that the ΔH°_{rxn} = -90.7 kJ? Explain! **(shifts to left because heat is a product when rxn. is exothermic, try to use up "excess" heat to re-establish equilibrium.)**
 - In the industrial process, the stoichiometric ratio of CO to H₂ is used. If the reaction is carried out at an initial total pressure of 300. bar, what are the initial partial pressures of CO and H₂? **(100. bar CO, 200. bar H₂)**

8. A flask initially contains only NOBr gas. Once heated to a temperature T, 20.0 % of the original gas decomposes via the following equation to give a total pressure of 0.33 bar at equilibrium:



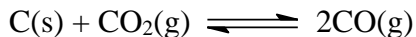
- Determine the original pressure of NOBr in the flask. **(0.30 bar)**
 - What is the value of K_p at this temperature T? **(1.9 x 10⁻³ or 3/1600)**
 - If the value of K_c at this temperature T is 3.9 x 10⁻⁵, determine the temperature T. **(600 K)**
9. For the equilibrium:



At some temperature T₁, K_p = 2.25. An unknown quantity of pure PCl₅(g) is placed in an evacuated flask and heated to T₁. When equilibrium was established, the partial pressure of PCl₅(g) was found to be 0.25 bar.

- What were the partial pressures of PCl₃ and Cl₂ at equilibrium? **(0.75 bar)**
- Determine the original pressure of PCl₅ (before any reaction) and the percent dissociation of PCl₅ at equilibrium. **(1.00 bar, 75 %)**
- What is the value of K_c for the reaction if T₁ is 327°C? **(about 5 x 10⁻²)**

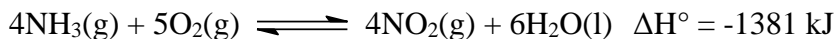
10. For the following system:



At 700.°C in a 2.00 L flask there are 0.100 moles of CO, 0.200 moles of CO₂, and 0.400 moles of C at equilibrium. At 600.°C, an additional 0.0400 moles of C forms at equilibrium.

- a) The process as written is: exothermic or **endothermic**
- b) Determine the value of K_c at 600.°C and 700.°C. (**K_c = 0.0250 at 700.°C, 8.3 x 10⁻⁴ at 600.°C**)
- c) An additional 0.200 moles of C is added to the flask at 600.°C. What will be the effect on:
- | | | | | |
|------|------------------|----------|----------|------------------|
| i) | K _c | increase | decrease | no effect |
| ii) | P _{CO} | increase | decrease | no effect |
| iii) | P _{CO2} | increase | decrease | no effect |

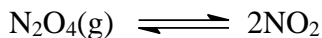
11. Consider the equilibrium:



Predict whether the equilibrium number of moles of NH₃ will increase or decrease and the direction that the reaction will shift in order to establish a new equilibrium if:

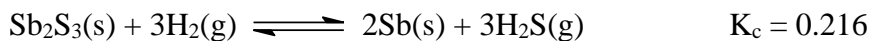
- i) the volume of the system is decreased (**↓, shifts to right**)
- ii) the temperature of the system is increased (**↑, shifts to left**)
- iii) some O₂ is added to the container (**↓, shifts to right**)
- iv) some He is added to the container (**no effect**)
- v) some NH₃ is added to the container (**↑, shifts to right**)
- vi) some H₂O is removed from the container (**no effect as long as some water remains**)

12. 0.50 moles of N₂O₄ were introduced into a 0.25 L flask. Determine the equilibrium concentrations of N₂O₄ and NO₂ if K_c for the equilibrium



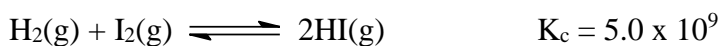
is 5.0 x 10⁻⁷. (**N₂O₄ = 2.0 M; NO₂ = 1.0 x 10⁻³ M**)

13. Some antimony sulfide and 500 mmol of H_2 were placed in a 500 mL flask and heated.
What were the equilibrium concentrations of H_2 and H_2S once equilibrium had been reached?



$$([\text{H}_2] = 0.625 \text{ M}; [\text{H}_2\text{S}] = 0.375 \text{ M})$$

14. 0.100 mol of H_2 and 0.100 mol of HI were placed in a 1.00 L container and heated.
Determine the equilibrium concentrations of all species.



$$([\text{H}_2] = [\text{HI}] = 0.100 \text{ M}, [\text{I}_2] = 2.0 \times 10^{-11} \text{ M})$$