6.3: Equilibrium Expressions Involving Pressures

When calculating equilibrium constants of solutions, the concentrations of each component in the solution are used to calculate K, which is the equilibrium constant. When working with concentrations, the equilibrium constant is designated as K_c. However, when working with a mixture of gases, concentrations are not used, but instead the gases' partial pressures. By first calculating the equilibrium constant in terms of pressure, designated K_p, K_c can then be calculated by using a simple formula.

1. Internal Links
2. Practice Problems
3. References
4. Contributors and Attributions

How do you begin writing the equilibrium constant for a mixture of gases?

To explain this clearly, let us look at a simple example, the reaction:

$$2NH_3(g) \text{ <---> } N_2(g) + 3H_2(g).$$

1) First, each component of the mixture in the equilibrium constant is written in terms of their activities. The activity of each component is the partial pressure of each component divided by their partial pressure "reference-states." Writing the equilibrium constant in terms of partial pressures requires it to be referred to as K_p.

$$K = ((a_{N2})(a_{H2})^3 \,/\, (a_{NH3})^2) \text{ eq}$$

$$a_{N2} = P_{N2}/P^o$$

$$a_{H2} = P_{H2}/P^o$$

$$a_{NH3} = P_{NH3}/P^o$$

2) Next, take the activities, showed in terms of pressure, of the products raised to the power of their coefficients, and divided by the activities of the reactants. The activities of the reactants are also raised to the power of their coefficients. To simplify the expression, the partial pressure "reference-state" of each component can be divided out.

$$K_p = ((P_{N2}/P^o)(P_{H2}/P^o)^3 \,/\, (P_{NH3}/P^o)^2) \text{ eq}$$

$$P^o \,((P_{N2})(P_{H2})^3/(P_{NH3})^2) \text{ eq}$$

3) To relate the pressures of this expression to concentrations, the ideal gas law is used. The ideal gas law is **PV=nRT**, where P is the pressure, V is the volume, n is the number of moles of the substnace, R is the constant 0.08206 L atm/K mol, and T is the temperature in Kelvins. By inverting the ideal gas law equation and solving for the concentration, n/V, or moles per liter, the concentrations of the gases are expressed by their partial pressures divided by RT.

$$\{N2\} = n/v = P_{N2}/RT$$

$$\{H2\} = n/V = P_{H2}/RT$$

$$\{NH3\} = n/V = P_{NH3}/RT$$

4) Now, since we have solved for the concentrations of each gas component, we write them in terms of concentration activities. This is the concentrations of each component divided by the concentration reference state.

$$a_{N2} = \{N2\}/c^o = (P_{N2}/RT)/c^o$$

$$a_{H2} = \{H2\}/c^o = (P_{H2}/RT)/c^o$$

$$a_{NH3} = \{NH3\}/c^o = (P_{NH3}/RT)/c^o$$

The last and final step is entering these activities into the expression we earlier derived in step 2 and dividing out RT.

$$K_p = P^o((\{N2\}RT)(\{H2\}RT)^3/(\{NH3\}RT)^2) \text{ eq}$$

$$K_p = (P^o/RT)(\{N2\}\{H2\}^3/\{NH3\}^2) \text{ eq}$$

This gives the equilibrium constant expression for a mixture of gases (K_p).

K_p and K_c can be related by setting the two equations equal to each other and divided out the reference states. This gives the simple formula:

$K_p = K_c(RT)^{\text{difference in coefficients of gas components only}}$

Please Note:

P^o is the partial pressure reference-state and it equals about 1 atm

c^o is the concentration reference-state and it equals about 1mol/L

eq is the term used to indicate that the components are at equilibrium

{x} is the concentration of the component x where x is a variable used to indicate a substance

Equilibrium constant expression do not include those components in a reaction that are pure solids or liquids (please refer to the corresponding internal link below)

Internal Links

- Writing equilibrium constant expressions involving solids and liquids
- Gas equilibrium constants, Kp and Kc?
- Meaning of the equilibrium constant, K

Practice Problems

1) Gas A and Gas B react to form Gas C. The reaction performed can be written as A(g)+B(g)

UndefinedNameError: reference to undefined name 'math' (click for details)

C(g). At equilibrium, the partial pressures of A, B, and C are 1 atm, 0.50 atm, and 0.75 atm respectively. Find K_p for the reaction.

Solution:

First, write out the equilibrium constant expression for K_p. K_p= P^o(

UndefinedNameError: reference to undefined name 'math' (click for details)

)eq

Remember that P^o= 1 bar which is essentially equal to 1 atm. Next, plug in the partial pressures for the corresponding gases.

K_p=

UndefinedNameError: reference to undefined name 'math' (click for details)

)

=1.5

2) A(g), at 750 mmHg, reacts with B(g), at 760 mmHg, to form C(g). K_p for the reaction is 1.5 X 10^{-5} and the reaction at equilibrium can be written A(g)+B(g)

UndefinedNameError: reference to undefined name 'math' (click for details)

2C(g). Find the partial pressure of C.

Solution

First set up the equilibrium constant expression for K_p. K_p= P^o(

UndefinedNameError: reference to undefined name 'math' (click for details)

)eq

C is raised to the power of 2 since 2 is the coefficient of C. Since we know K_p we can subsitute that into the equation. Also, convert the partial pressure of A and B to atm. P_A= 750 mmHg X

UndefinedNameError: reference to undefined name 'math' (click for details)

=0.98684 & P_B= 1 atm

$1.5 \text{ X } 10^5$ =

UndefinedNameError: reference to undefined name 'math' (click for details)

$(1.5 \text{ X}10^{-5})(0.98684)= C^2$

$\text{sqrt}(1.48026\text{X}10^{-5})=C$

$C= 3.8474147\text{X}10^{-3}$ or $C= 3.9\text{X}10^{-3}$

3) For the following reaction at equilibrium $2SO_2(g)+ O_2$

UndefinedNameError: reference to undefined name 'math' (click for details)

$2SO_3(g)$ K_p is 3.4 at 1000K. What is K_c for the reaction?

Solution:

We know that $K_p=K_c(RT)^{(\text{Difference in coefficients of gaseous products and reactants})}$

We also know K_p= 3.4, R is a constant which is 0.08206L atm $mol^{-1}K^{-1}$, T=1000K

(RT) is raised to the power of (Difference in coefficients of gaseous products and reactants) so since **2**$SO_2(g)$+ **1**O_2

UndefinedNameError: reference to undefined name 'math' (click for details)

2$SO_3(g)$ (Difference in coefficients of gaseous products and reactants)= (2)-(2+1)= -1

Rewrite the equation, $K_p=K_c(RT)^{(\text{Difference in coefficients of gaseous products and reactants})}$, to solve for Kc and subsitute in the values. ^K_c=

UndefinedNameError: reference to undefined name 'math' (click for details)

$K_c= 2.79\text{X}10^2$

4) For the following reaction at equilibrium, $N_2(g)+ 3H_2(g)$

UndefinedNameError: reference to undefined name 'math' (click for details)

$2NH_3(g)$, K_p is $2.25\text{X}10^{-6}$. If the values of the partial pressures of N_2 and NH_3 are $3.5\text{X}10^{-3}$ and $2.0\text{X}10^{-5}$ respectively, what is the partial pressure of H_2?

Solution

Set up the equilibrium constant expression for K_p. K_p= K_p= P^o

UndefinedNameError: reference to undefined name 'math' (click for details)

eq

Substitute the values in to the correct places.

$2.25X10^{-6}$=

UndefinedNameError: reference to undefined name 'math' (click for details)

UndefinedNameError: reference to undefined name 'math' (click for details)

=

UndefinedNameError: reference to undefined name 'math' (click for details)

UndefinedNameError: reference to undefined name 'math' (click for details)

=0.0507936508

Take the cubed root of the number to find the Partial pressure of H_2

UndefinedNameError: reference to undefined name 'math' (click for details)

=0.37 atm

5) 1 mol of A and 1 mol of B are placed in a 2.0 L flask. The following reaction at equilibrium is established at 500K. A(g)+B(g)

UndefinedNameError: reference to undefined name 'math' (click for details)

C(g) K_p= 15.0 For the equilibrium established, find the partial pressure of C.

Solution

First, we must find the partial pressures of A and B. We know that by using P=

UndefinedNameError: reference to undefined name 'math' (click for details)

, we can say P_A=P_B=

UndefinedNameError: reference to undefined name 'math' (click for details)

= 20.515

Now create an ICE table.

A(g) + B(g)

UndefinedNameError: reference to undefined name 'math' (click for details)

C(g)

I 20.515 20.515 0

C -x -x +x

E (20.515-x) (20.515-x) (x)

Now set up the equilibrium constant expression for K_p= 15.0=

UndefinedNameError: reference to undefined name 'math' (click for details)

$15(20.515-x)^2= x$ Use FOIL

$15(420.865225-41.03x+x^2)= x$ distribute & multiply by 15

$15x^2-615.45x+6312.978375=x$ subtract the x to make the equation equal to 0

$15x^2-616.45x+6312.978375=0$ Use the quadratic formula

UndefinedNameError: reference to undefined name 'math' (click for details)

and

UndefinedNameError: reference to undefined name 'math' (click for details)

a=15 b=-616.45 c= 6312.978375

UndefinedNameError: reference to undefined name 'math' (click for details)

and

UndefinedNameError: reference to undefined name 'math' (click for details)

We find that there are two solutions. P_C= 19.38 or 21.7

19.38 is the correct solution since 21.7 is too large.

References

1. Petrucci, Ralph H., et al. General Chemistry: Principles and Modern Applications. Upper Saddle River, NJ: Prentice Hall, 2007.

Contributors and Attributions

- Kathryn Rashel
- Lisa Peterson
- Kyle Catabay (UCD)

6.3: Equilibrium Expressions Involving Pressures is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by LibreTexts.

- **Writing Equilibrium Constant Expressions Involving Gases** is licensed CC BY-NC-SA 4.0.