# Chemistry 12
# Worksheet 2-3
# Calculations Involving the Equilibrium Constant $K_{eq}$ )

1. Given the equilibrium equation below:

$$A_{2(g)} + B_{2(g)} \rightleftarrows 2AB_{(g)}$$

If, *at equilibrium*, the concentrations are as follows:

$[A_2] = 3.45$ M, $[B_2] = 5.67$ M and $[AB] = 0.67$ M

a) Write the **expression** for the equilibrium constant, $K_{eq}$

$$K_e = \frac{[AB]^2}{[A_2][B_2]}$$

b) Find the **value** of the equilibrium constant, $K_{eq}$ at the temperature that the experiment was done.

$$K_e = \frac{(0.67)^2}{(3.45)(5.67)}$$

Answer 0.023

2. Given the equilibrium equation:

$$X_{2(g)} + 3Y_{2(g)} \rightleftarrows 2XY_{3(g)}$$

at a temperature of 50°C, it is found that when equilibrium is reached that:

$[X_2] = 0.37$ M, $[Y_2] = 0.53$ M and $[XY_3] = 0.090$ M

a) Write the **equilibrium constant expression** ($K_{eq}$ )

$$K_e = \frac{[XY_3]^2}{[X_2][Y_2]^3}$$

b) Calculate the **value** of $K_{eq}$ at 50°C.

$$K_e = \frac{(0.090)^2}{(0.37)(0.53)^3}$$

Answer 0.078

3. For the reaction: $A_{2(g)} + B_{(g)} \rightleftarrows 2C_{(g)}$

it is found that by adding 1.5 moles of C to a 1.0 L container, an equilibrium is established in which 0.30 moles of B are found. (*Hint: Make a table and use it to answer the questions below.*)

| | $A_2$ | + | $B$ | $\rightleftharpoons$ | $2C$ |
|---|---|---|---|---|---|
| I | 0 | | 0 | | 1.5 |
| C | +x | | +x | | -2x |
| E | x | | x | | 1.5 - 2x |

$0.30 = x$

a) What is [A] at equilibrium? Answer 0.30 M

b) What is [B] at equilibrium? Answer 0.30 M

c) What is [C] at equilibrium? Answer 0.90 M

d) Write the **expression** for the equilibrium constant, $K_{eq}$.

$$K_e = \frac{[C]^2}{[A_2][B]}$$

e) Calculate the **value** for the equilibrium constant at the temperature at the experiment was done.

$$K_e = \frac{(0.90)^2}{(0.30)(0.30)}$$

Answer 9.0

c) In another equilibrium mixture at the same temperature, it is found that [A] = 0.35 M and the [C] = 0.86 M. From this and the information above, calculate the *equilibrium [B]*.

$$A_{(g)} + B_{(g)} \rightleftarrows C_{(g)}$$

$$1.06 = \frac{(0.86)}{(0.35)B}$$

Answer 2.32 M.

6. Two mole of gaseous $NH_3$ are introduced into a 1.0 L vessel and allowed to undergo partial decomposition at high temperature according to the reaction:

$$2NH_{3(g)} \rightleftarrows N_{2(g)} + 3H_{2(g)}$$

At equilibrium, 1.0 mole of $NH_{3(g)}$ remains.
(*Make a table and use it to answer the questions below:*)

| | $2NH_3$ | $\rightleftarrows$ | $N_2$ | + | $3H_2$ |
|---|---|---|---|---|---|
| I | 2.0 | | 0 | | 0 |
| C | -2x | | +x | | +3x |
| E | 2.0-2x | | x | | 3x |

$$2.0 - 2x = 1.0$$
$$x = 0.50$$

a) What is the equilibrium $[N_2]$? Answer 0.50 M

b) What is the equilibrium $[H_2]$? Answer 1.50 M

c) Calculate the **value** of the equilibrium constant at the temperature of the experiment.

$$K_e = \frac{[N_2][H_2]^3}{[NH_3]^2}$$
$$= \frac{(0.50)(1.50)^3}{(1.0)^2}$$

Answer 1.69

4. Considering the following equilibrium:

$$2AB_{3(g)} \rightleftarrows A_{2(g)} + 3B_{2(g)}$$

If 0.87 moles of $AB_3$ are injected into a 5.0 L container at 25°C , at equilibrium the final $[A_2]$ is found to be 0.070 M.(*Hint: Make a table and use it to answer the questions below.*)

| | $2AB_3$ | $\rightleftharpoons$ | $A_2$ | + | $3B_2$ |
|---|---|---|---|---|---|
| I | 0.174 | | 0 | | 0 |
| C | $-2x$ | | $+x$ | | $+3x$ |
| E | $0.174-2x$ | | $x$ | | $3x$ |

$$[A_2] = 0.070\ M = x$$

a) Calculate the equilibrium concentration of $AB_3$. Answer 0.034 M

b) Calculate the equilibrium $[A_2]$. Answer 0.070 M

c) Calculate the equilibrium $[B_2]$. Answer 0.21 M.

5. Consider the reaction:

$$A_{(g)} + B_{(g)} \rightleftarrows C_{(g)}$$

a) In an equilibrium mixture the following concentrations were found:

[A] = 0.45M, [B] = 0.63M and [C] = 0.30M. Calculate the value of the equilibrium constant for this reaction.

$$K_e = \frac{[C]}{[A][B]} = \frac{0.30}{(0.45)(0.63)}$$ Answer 1.06

b) At the same temperature, another equilibrium mixture is analyzed and it is found that [B] = 0.21 M and [C] = 0.70 M. From this and the information above, calculate the *equilibrium [A]*.

$$1.06 = \frac{0.70}{(0.21)A}$$

Answer 3.14 M.

7. At a high temperature, 0.50 mol of HBr was placed in a 1.0 L container and allowed to decompose according to the reaction:

$$2HBr_{(g)} \rightleftarrows H_{2(g)} + Br_{2(g)}$$

At equilibrium the $[Br_2]$ was measured to be 0.13 M. What is $K_{eq}$ for this reaction at this temperature?

| | $2HBr$ | $\rightleftarrows$ | $H_2$ | + | $Br_2$ |
|---|---|---|---|---|---|
| I | 0.50 | | 0 | | 0 |
| C | $-2x$ | | $+x$ | | $+x$ |
| E | $0.50-2x$ | | $x$ | | $x$ |

$x = 0.13 = [H_2]_e = [Br_2]_e$

$[HBr]_e = 0.24$

Answer 0.29

8. When 1.0 mol of $NH_{3(g)}$ and 0.40 mol of $N_{2(g)}$ are placed in a 5.0 L vessel and allowed to reach equilibrium at a certain temperature, it is found that 0.78 mol of $NH_3$ is present. The reaction is:

| | $2NH_{3(g)}$ | $\rightleftarrows$ | $3H_{2(g)}$ | + | $N_{2(g)}$ |
|---|---|---|---|---|---|
| I | 0.20 | | 0 | | 0.08 |
| C | $-2x$ | | $+3x$ | | $-x$ |
| E | $0.20-2x$ | | $3x$ | | $0.08-x$ |

omit.

$0.20 - 2(0.156) =$

a) Calculate the **equilibrium concentrations** of all three species.

$[NH_3] =$ _____ $[H_2] =$ _____ $[N_2] =$ _____

b) Calculate the **value** of the equilibrium constant at this temperature.

Answer _____

c) How many **moles** of $H_2$ are present at equilibrium?

Answer _____

d) How many **moles** of $N_2$ are present at equilibrium?

Answer _____

9. When 0.40 mol of $PCl_5$ is heated in a 10.0 L container, an equilibrium is established in which 0.25 mol of $Cl_2$ is present. (*Make a table and answer the questions below. Be sure to read all questions a-d before making your table!:*)

| $PCl_{5(g)}$ | ⇄ | $PCl_{3(g)}$ | + | $Cl_{2(g)}$ | |
|---|---|---|---|---|---|
| 0.04 | | 0 | | 0 | $x = [Cl_2] = 0.025$ |
| − x | | +x | | +x | |
| 0.04 − x | | x | | x | |

a) Calculate the **equilibrium concentration** of each species.

$[PCl_5]$ = 0.015 M $[PCl_3]$ = 0.025 M $[Cl_2]$ = 0.025 M

b) Calculate the **value** of the equilibrium constant, $K_{eq}$ at the temperature of the experiment.

$$K_e = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{(0.025)(0.025)}{0.015}$$

Answer 0.042

c) What **amount** (moles) of $PCl_3$ is present at equilibrium?

Answer 0.25 mol

d) What **amount** (moles) of $PCl_5$ is present at equilibrium?

Answer 0.15 mol

10. A mixture of $H_2$ and $I_2$ is allowed to react at 448°C. When *equilibrium* is established, the concentrations of the participants are found to be:

$[H_2] = 0.46$ M, $[I_2] = 0.39$ M and $[HI] = 3.0$ M.

The equation is: $H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)}$

a) Calculate the **value** of $K_{eq}$ at 448°C.

$$\frac{(3.0)^2}{(0.46)(0.39)}$$

Answer 50.17

b) In another equilibrium mixture of the *same* participants at 448°C , the concentrations of $I_2$ and $H_2$ are both 0.050 M. What is the *equilibrium concentration* of HI?

$$50.19 = \frac{[HI]^2}{(0.050)(0.050)}$$

Answer 0.35 M

11. The $K_{eq}$ for the reaction:

$$PCl_{5(g)} \rightleftarrows PCl_{3(g)} + Cl_{2(g)}$$

at 250°C is found to be ***0.042***. In an *equilibrium mixture* of these species, it is found that $[PCl_5] = 0.012$ M, and $[Cl_2] = 0.049$ M. What is the equilibrium $[PCl_3]$ at 250°C ?

$$0.042 = \frac{[PCl_3](0.049)}{(0.012)}$$

Answer 0.010 M

12. At a certain temperature the reaction:

$$CO_{(g)} + 2H_{2(g)} \rightleftarrows CH_3OH_{(g)}$$

has a Keq = ***0.500***. If a reaction mixture at equilibrium contains 0.210 M CO and 0.100 M $H_2$ , what is the *equilibrium* $[CH_3OH]$?

$$0.500 = \frac{[CH_3OH]}{(0.210)(0.100)^2}$$

Answer $1.05 \times 10^{-3}$ M

13. At a certain temperature the reaction: $CO_{(g)} + H_2O_{(g)} \rightleftarrows CO_{2(g)} + H_{2(g)}$

has a $K_{eq} = 0.400$. Exactly *1.00 mol* of each gas was placed in a 100.0 L vessel and the mixture was allowed to react. Find the **equilibrium concentration** of each gas.

| | $CO$ | + $H_2O$ | $\rightleftharpoons$ $CO_2$ | + $H_2$ |
|---|---|---|---|---|
| I | 0.01 | 0.01 | 0.01 | 0.01 |
| C | $-x$ | $-x$ | $-x$ | $-x$ |
| E | $0.01-x$ | $0.01-x$ | $0.01-x$ | $0.01-x$ |

$$0.400 = \frac{(0.01-x)^2}{(0.01-x)^2}$$

$$0.632 = \frac{0.01-x}{0.01-x}$$

$$6.32\times10^{-3} - 0.632x = 0.01 - x$$

$$-0.632x + x = 0.01 - 6.32\times10^{-3}$$

$$0.368x = 3.68\times10^{-3}$$

Answer 0.01 M.

14. The reaction: $2XY_{(g)} \rightleftarrows X_{2(g)} + Y_{2(g)}$

has a $K_{eq} = 35$ at 25°C. If 3.0 moles of XY are injected into a 1.0 L container at 25°C , find the equilibrium $[X_2]$ and $[Y_2]$.

| | $2XY$ | $\rightleftharpoons$ $X_2$ | + $Y_2$ |
|---|---|---|---|
| I | 3.0M | 0 | 0 |
| C | $-2x$ | $+x$ | $+x$ |
| E | $3.0-2x$ | $x$ | $x$ |

$$K_e = 35 = \frac{[X_2][Y_2]}{[XY]^2}$$

$$35 = \frac{(x)(x)}{(3.0-2x)^2}$$

$$35 = \frac{x^2}{(3.0-2x)^2}$$

$$5.92 = \frac{x}{3.0-2x}$$

$$17.75 - 11.84x = x$$

$$17.75 = 12.84x$$

$$1.38 = x$$

Answer $[X_2] = 1.38M$ $[Y_2] = 1.38$ M.

$XY = 0.24M$.

15. The equilibrium constant for the reaction:

$$H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)} \qquad \text{at } 448°C \text{ is } \textbf{\textit{50}}.$$

a) If 1.0 mol of $H_2$ is mixed with 1.0 mol of $I_2$ in a 0.50 L container and allowed to react at 448°C, what is the **equilibrium** [HI]?

| | $H_2$ | + | $I_2$ | ⇌ | $2HI$ |
|---|---|---|---|---|---|
| I | 2.0 | | 2.0 | | 0 |
| C | −x | | −x | | +2x |
| E | 2.0−x | | 2.0−x | | 2x |

$$50 = \frac{[HI]^2}{[H_2][I_2]}$$

$$50 = \frac{(2x)^2}{(2.0-x)^2}$$

$$7.07 = \frac{2x}{2.0-x}$$

$$14.14 - 7.07x = 2x$$

$$14.14 = 9.07x$$

$$x = 1.56$$

Answer 3.12 M.

b) How many **moles** of HI are formed at equilibrium? (Actual yield)

Answer 1.56 mol.

16. Given $K_{eq}$ for the reaction:

$$PCl_{5(g)} \rightleftarrows PCl_{3(g)} + Cl_{2(g)}$$

is ***0.042*** at 250°C, what will happen if 2.50 mol of $PCl_5$, 0.600 mol of $Cl_2$ and 0.600 mol of $PCl_3$ are placed in a 1.00 flask at 250°C ? (*Will the reaction shift left, right, or not occur at all?*)

omit

| | $PCl_5$ | ⇌ | $PCl_3$ | + | $Cl_2$ |
|---|---|---|---|---|---|
| I | 2.50 | | 0.600 | | 0.600 |
| C | −x | | −x | | −x |
| E | 2.50−x | | 0.600−x | | 0.600−x |

$$0.042 = \frac{(0.600-x)(0.600-x)}{(2.50-x)}$$

$$0.105 - 0.042x = 0.36 - 1.2x + x^2$$

$$x^2 - 1.2x + 0.042x + 0.36 - 0.105$$

$$x^2 - 1.158x + 0.255$$

$x = 0.296$ (used quad eqn).

$[PCl_3]_e = [Cl_2]_e = 0.304$ M

$[PCl_5]_e = 2.204$

$$Q = \frac{(0.304)^2}{2.204}$$

$$Q = 0.0419.$$

Answer @ equil.

17. Given the equilibrium equation: $H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)}$

at 448°C, $K_{eq}$ = ***50.*** If 3.0 mol of HI, 2.0 mol of $H_2$, and 1.5 mol of $I_2$ are placed in a 1.0 L container at 448°C, will a reaction occur?

omit

$H_2 + I_2 \rightleftarrows 2HI$

I 2.0 1.5 3.0

C −x −x +2x

E 2.0−x 1.5−x 3.0+2x

$50 = \frac{(3.0+2x)^2}{(2.0-x)(1.5-x)}$

$50 = \frac{9.0+12x+4x^2}{3.0-3.5x+x^2}$

$150 - 175x + 50x^2 = 9.0 + 12x + 4x^2$

$46x^2 - 163x + 141 = 0$

$x = 1.5$ $[H_2]_e = 0.5$ $[HI]_e = 0$

$[I_2]_e = 0$ $Q = \frac{0^2}{(0.5)(0)}$

Answer NO

If so, which way does the reaction shift? _____

18. Given the equilibrium equation: $H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)}$

at 448°C, $K_{eq}$ = ***50.*** If 5.0 mol of HI, 0.7071 mol of $H_2$, and 0.7071 mol of $I_2$ are placed in a 1.0 L container at 448°C, will a reaction occur? (*Round any answers off to 3 significant digits!*)

omit

Answer _____

If so, which way does the reaction shift? _____

19. Determine the equilibrium constant for the reaction: $H_{2(g)} + I_{2(g)} \rightleftarrows 2HI_{(g)}$ given that an equilibrium mixture is analyzed and found to contain the following concentrations: $[H_2] = 0.0075$ M, $[I_2] = 0.000043$ M and $[HI] = 0.0040$ M

$K_e = \frac{(0.0040)^2}{(0.0075)(0.000043)}$

$K_e =$

Answer 49.61

20. Given the equilibrium equation: $3A_{(g)} + B_{(g)} \rightleftarrows 2C_{(g)}$

If 2.50 moles of A and 0.500 moles of B are added to a 2.00 L container, an equilibrium is established in which the [C] is found to be 0.250 M.

a) Find [A] and [B] at equilibrium.

| | 3A | + B | ⇌ 2C |
|---|---|---|---|
| I | 1.25 | 0.25 | 0 |
| C | −3x | −x | +2x |
| E | 1.25 − 3x | 0.25 − x | 2x |

$2x = 0.250$
$x = 0.125$

Answer $[A]_e = 0.875\ M$, $[B]_e = 0.125\ M$.

b) Calculate the value of the equilibrium constant $K_{eq}$.

$$K_e = \frac{(0.250)^2}{(0.875)(0.125)}$$

Answer 0.57

21. At 800°C, the equilibrium constant $K_{eq}$, for the reaction:

$$CO_{2(g)} + H_{2(g)} \rightleftarrows CO_{(g)} + H_2O_{(g)} \quad \text{is } 0.279$$

If 1.50 moles of $CO_2$ and 1.50 moles of $H_2$ are added to a 1.00 L container, what would the [CO] be at equilibrium?

| | $CO_2$ | + $H_2$ | ⇌ CO | + $H_2O$ |
|---|---|---|---|---|
| I | 1.50 | 1.50 | 0 | 0 |
| C | −x | −x | +x | +x |
| E | 1.5 − x | 1.5 − x | x | x |

$$0.279 = \frac{(x)(x)}{(1.5-x)^2}$$

$$0.279 = \frac{x^2}{(1.5-x)^2}$$

$$0.528 = \frac{x}{1.5-x}$$

$0.79 - 0.528x = x$
$x = 0.519$

Answer 0.52 M.

22. Given that the equilibrium constant $K_{eq}$ for the reaction:

$$A_{(g)} + B_{(g)} \rightleftarrows C_{(g)} + D_{(g)}$$ is ***0.015*** at 25°C,

if 1.0 mole of each gas is added to a 1.0 L container at 25°C, which way will the equation shift in order to reach equilibrium?

omit

Answer _____

23. Calculate the **equilibrium constant** $K_{eq}$ for the following reaction:

$$2A_{2(g)} + 3B_{2(g)} \rightleftarrows 2A_2B_{3(g)}$$

given that the *partial pressure* of each substance at equilibrium is as follows:

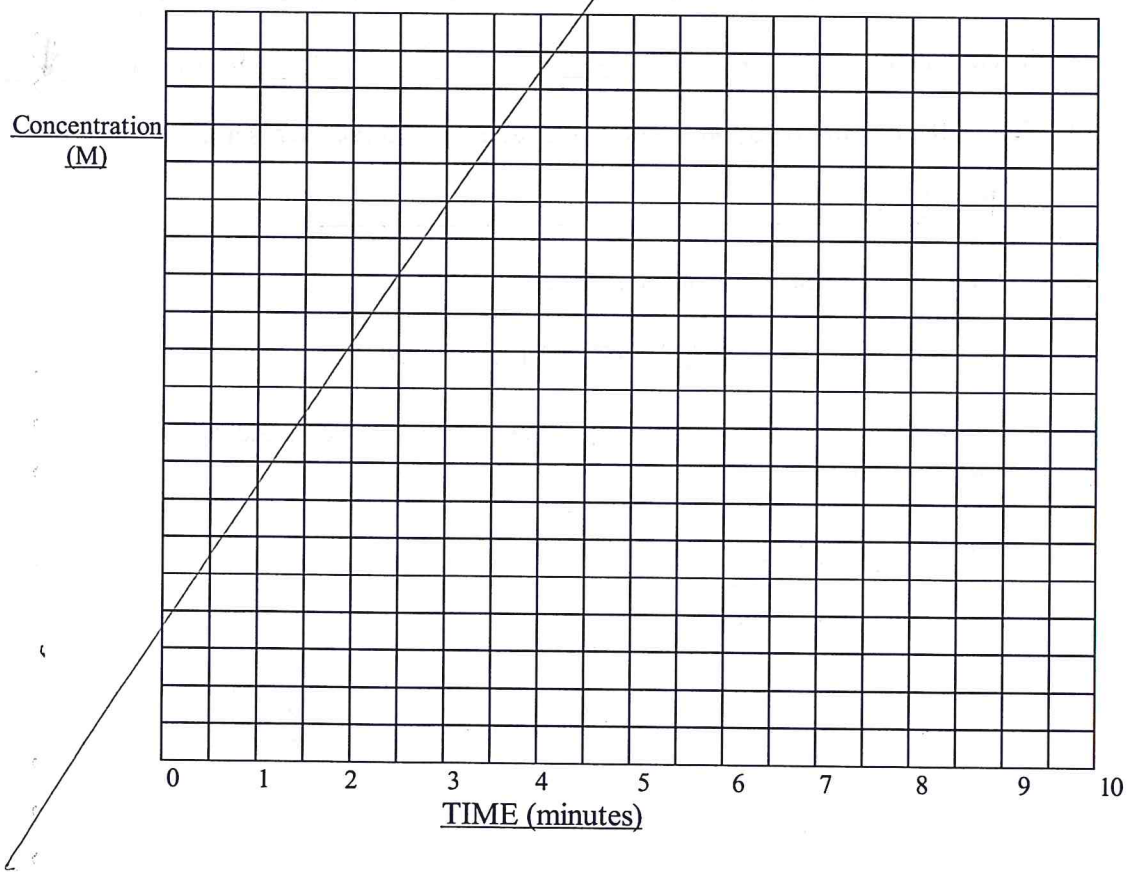
Partial Pressure of $A_2$ = 20.0 kPa, Partial Pressure of $B_2$ = 30.0 kPa, Partial Pressure of $A_2B_3$ = 5.00 kPa.

omit.

Answer _____

24. Consider the following equilibrium system: $A_{(g)} + B_{(g)} \rightleftarrows C_{(g)}$

1.0 mole of A and 2.0 moles of B are simultaneously injected into an empty 1.0 L container. At equilibrium (after 5.0 minutes), [C] is found to be 0.20 M. Make calculations and draw graphs to show how each of [A], [B] and [C] change with time over a period of 10.0 minutes. (*HINT: You have to make a table first.*)



25. Given the reaction:

$$4HCl_{(g)} + O_{2(g)} \rightleftarrows 2H_2O_{(g)} + 2Cl_{2(g)} \quad \Delta H = -113 \text{ kJ}$$

How will the value of the equilibrium constant $K_{eq}$ at 550°C compare with it's value at 450°C? adding. exo... so heat shifts to Left ∴ ↑[HCl] + [O₂]

~~Explain your answer.~~ Ke ↓

removing heat = Ke ↑

26. The following system is at equilibrium, in a closed container:

$$4NH_{3(g)} + 3O_{2(g)} \rightleftarrows 6H_2O_{(g)} + 2N_{2(g)} + \text{Heat}$$

a) How is the *amount of N2* in the container affected if the ***volume*** of the container is ***doubled***? ↑V = ↓P so shifts R ∴ [N₂] = ↑

b) How is the rate of the **forward reaction** affected if more water vapor is introduced into the container? ↑ H₂O shift L ∴ → Rⁿ is ↓

c) How is the amount of $O_2$ in the container affected if a *catalyst* is added?

N.C.

27. At a certain temperature, $K_{eq}$ for the reaction:

$$3C_2H_2 \rightleftarrows C_6H_6 \text{ is } \mathbf{5.0}.$$

If the *equilibrium concentration* of $C_2H_2$ is 0.40 moles/L, what is the *equilibrium concentration* of $C_6H_6$?

$$5.0 = \frac{[C_6H_6]}{(0.40)^3}$$

Answer 0.32 M.