Chemistry 12

CALCULATIONS INVOLVING THE EQUILIBRIUM CONSTANT KEQ)

KEY

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}

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

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

$$K_{eq} = \frac{(0.67)^2}{(3.45)(5.67)} = \boxed{2.3 \times 10^{-2}}$$

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})

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

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

$$K_{eq} = \frac{(0.090)^2}{(0.37)(.53)^3} = \boxed{0.15}$$

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_2 $\rightleftharpoons$	$2C$
I	0	0	1.5M
C	+0.30	+ 0.30	-0.60
E	0.30M	0.30M	0.9M

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

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

c) What is [C] at equilibrium? 0.9M

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

$$K_{eq} = \frac{[C]^2}{[A_2][B_2]} = \frac{(0.9)^2}{(0.30)(0.30)} = 9$$

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

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.*)

	$2AB_3 \rightleftarrows$	A_2 +	$3B_2$
I	0.174M	0	0
C	−0.14M	+0.070M	+0.21M
E	0.034M	0.070M	0.21M

↑ to 2dp.

$[AB_3] = \frac{0.87 mol}{5.0 L} = 0.174M$

a) Calculate the equilibrium concentration of AB_3. 0.03 M

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

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

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.

$$Keq = \frac{[C]}{[A][B]} = \frac{0.30}{(.45)(.63)} = 1.1$$

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]*.

$$[A] = \frac{[C]}{Keq[B]} = \frac{0.70}{(1.0582)(0.21)} = 3.2M$$

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].*

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

$$[B] = \frac{[C]}{[A](Keq)} = \frac{0.86}{(.35)(1.0582)} = 2.3M$$

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:*)

	$2NH_3$ $\rightleftharpoons$	N_2 +	$3H_2$
I	2.0M	0	0
C	−1.0M	+0.5M	1.5M
E	1.0M	0.5M	1.5M

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

b) What is the equilibrium [H_2]? 1.5M

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

$$Keq = \frac{[N_2][H_2]^3}{[NH_3]^2} = \frac{(0.50)(1.5)^3}{(1.0)^2} = 1.7$$

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 ⇌	H_2 +	Br_2
I	0.50M	⊖	⊖
C	- 0.26M	+0.13M	+ 0.13M
E	0.24M	0.13M	0.13M

$Keq = \frac{[H_2][Br_2]}{[HBr]^2} = \frac{(.13)(.13)}{(.24)^2} = 0.29$

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:

	$2NH_{3(g)}$ ⇌	$3H_{2(g)}$ +	$N_{2(g)}$
I	0.20M	⊖	0.080M
C	-0.044M	+.066M	+0.022M
E	0.156M	0.066M	0.102M

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

[NH_3] = 0.16M [H_2] = 0.066 M [N_2] = 0.10M

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

$Keq = \frac{[H_2]^3[N_2]}{[NH_3]^2} = \frac{(0.066)^3(.102)}{(.156)^2} = 1.2 \times 10^{-3}$

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

mol $H_2 = \left(0.066 \frac{mol}{L}\right)(5.0L) = 0.33$ mol H_2

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

mol $N_2 = \left(0.102 \frac{mol}{L}\right)(5.0L) = 0.51$ mol N_2

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!:*)

	$PCl_{5(g)}$ $\rightleftarrows$	$PCl_{3(g)}$ +	$Cl_{2(g)}$
I	0.04M	0	0
C	-.025M	+0.025M	+ 0.025M
E	0.015M	0.025M	.025M

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

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

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

$$Keq = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{(.025)(.025)}{.015} = 0.042$$

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

$$mol\ PCl_3 = \left(0.025\frac{mol}{L}\right)(10.0L) = 0.25 mol\ PCl_3$$

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

$$mol\ PCl_5 = (0.015M)(10.0L) = 0.15 mol\ PCl_5$$

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.

$$Keq = \frac{[HI]^2}{[H_2][I_2]} = \frac{(3.0)^2}{(.46)(.39)} = 50. \text{ or } 5.0\times10^1$$

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?

$[HI]^2 = (Keq)[H_2][I_2]$
$= (50)(0.050)(0.050)$
$= 0.125$

$[HI]_{eq} = 0.35M$

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 ?

$Keq = \frac{[PCl_3][Cl_2]}{[PCl_5]}$ $[PCl_3] = \frac{Keq[PCl_5]}{[Cl_2]}$
$= \frac{(0.042)(0.012)}{(0.049)}$
$= \boxed{0.010M}$

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* $[CH_3OH]$?

$Keq = \frac{[CH_3OH]}{[CO][H_2]^2}$

$[CH_3OH] = (Keq)[CO][H_2]^2$
$= (0.500)(0.210)(0.100)^2$
$= \boxed{1.05 \times 10^{-3} M}$

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

has a $K_{eq} = \mathbf{0.400}$. 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	$+ H_2O \rightleftarrows$	CO_2	$+ H_2$
I	.01M	.01M	.01M	.01M
C	+x	+x	−x	−x
E	.01+x	.01+x	.01−x	.01−x

$K_{eq} = 0.400$

⇒ bottom must be bigger

$$K_{eq} = \frac{[CO_2][H_2]}{[CO][H_2O]}$$

$$\sqrt{0.400} = \sqrt{\frac{(.01-x)^2}{(.01+x)^2}}$$

$$.6324555 = \frac{.01-x}{.01+x}$$

$$.01-x = (.6346)(.01+x)$$

$$.01-x = .0063246 + .63246x$$

$$.003675 = 1.63246x$$

$$x = 0.0022512$$

$\left.\begin{matrix}[CO]_{eq} \\ [H_2O]_{eq}\end{matrix}\right\} = .0123M$

$\left.\begin{matrix}[CO_2]_{eq} \\ [H_2]_{eq}\end{matrix}\right\} = .0078M$

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

has a $K_{eq} = \mathbf{35}$ 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 $[Y_2]$.

	$2XY \rightleftarrows$	X_2	$+ Y$
I	3.0M	0	0
C	−2x	+x	+x
E	3.0−2x	x	x

$$K_{eq} = \frac{[X_2][Y]}{[XY]^2} = \frac{x^2}{(3.0-2x)^2} = 35$$

$$\frac{x}{3.0-2x} = 5.9160798$$

$$x = 5.91608(3-2x)$$

$$x = 17.7482 - 11.83216x$$

$$12.83216x = 17.7482$$

$$x = 1.3831$$

$[X_2]_{eq} = [Y_2]_{eq}$ ↗ 1.4M

15. The equilibrium constant for the reaction:

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

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	2.0M	2.0M	0
C	$-x$	$-x$	$+2x$
E	$2.0-x$	$2.0-x$	$2x$

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

$$\frac{2x}{2.0-x} = 7.071068$$

$$2x = 7.071068(2.0-x)$$

$$2x = 14.1421 - 7.071068x$$

$$9.071068x = 14.1421$$

$$x = 1.5590$$

$$\boxed{[HI] = 3.1M}$$

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

$$\text{moles HI} = \left(3.\cancel{0}\tfrac{mol}{L}\right)(.5L) = \boxed{1.6\ mol}$$

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?*)

$$Q = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{(.6M)(.6M)}{2.5M} = 0.144$$

$$Q > K_{eq}$$

$$0.144 \qquad 0.042$$

Shifts left

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?

$Q = K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = \frac{(3.0)^2}{(2.0)(1.5)} = 3$ $\quad \underset{3}{Q} < \underset{50}{K_{eq}}$

Shifts right

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!*)

$Q = \frac{(5)^2}{(.7071)(.7071)} = 50$ $\quad Q = K_{eq}$

$\Rightarrow$ no rxn.

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

$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.0040)^2}{(.0075)(.000043)} = \underline{\underline{50.}}$

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	1.25M	0.250M	0
C	−.375M	−.125M	+0.25M
E	0.875M	.125M	0.25M

↑ 2dp

$[A]_{eq} = 0.875M = \underline{0.88M}$

$[B]_{eq} = 0.125M$

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

$$K_{eq} = \frac{[C]^2}{[A]^3[B]} = \frac{(0.25)^2}{(.875)^3(.125)} = 0.746 = 0.75$$

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

$CO_{2(g)} + H_{2(g)} \rightleftarrows CO_{(g)} + H_2O_{(g)}$ 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	1.50M	1.50M	0	0
C	−x	−x	+x	+x
E	1.50−x	1.50−x	x	x

$$\frac{x^2}{(1.50-x)^2} = 0.279$$

$$\frac{x}{1.50-x} = 0.5282$$

$x = 0.5282(1.50-x)$

$x = 0.723 - .5282x$

$1.5282x = 0.723$

$x = 0.518$

$[CO]_{eq} = 0.518M$

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

$$A_{(g)} + B_{(g)} \rightleftarrows C_{(g)} + D_{(g)} \quad \text{is } \boldsymbol{0.015} \text{ at } 25^oC,$$

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?

$$Q = \frac{[C][D]}{[A][B]} = \frac{(1.0)(1.0)}{(1.0)(1.0)} = 1.0$$

$$\underset{1.0}{Q} > \underset{0.015}{Keq} \qquad \text{shifts left}$$

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:

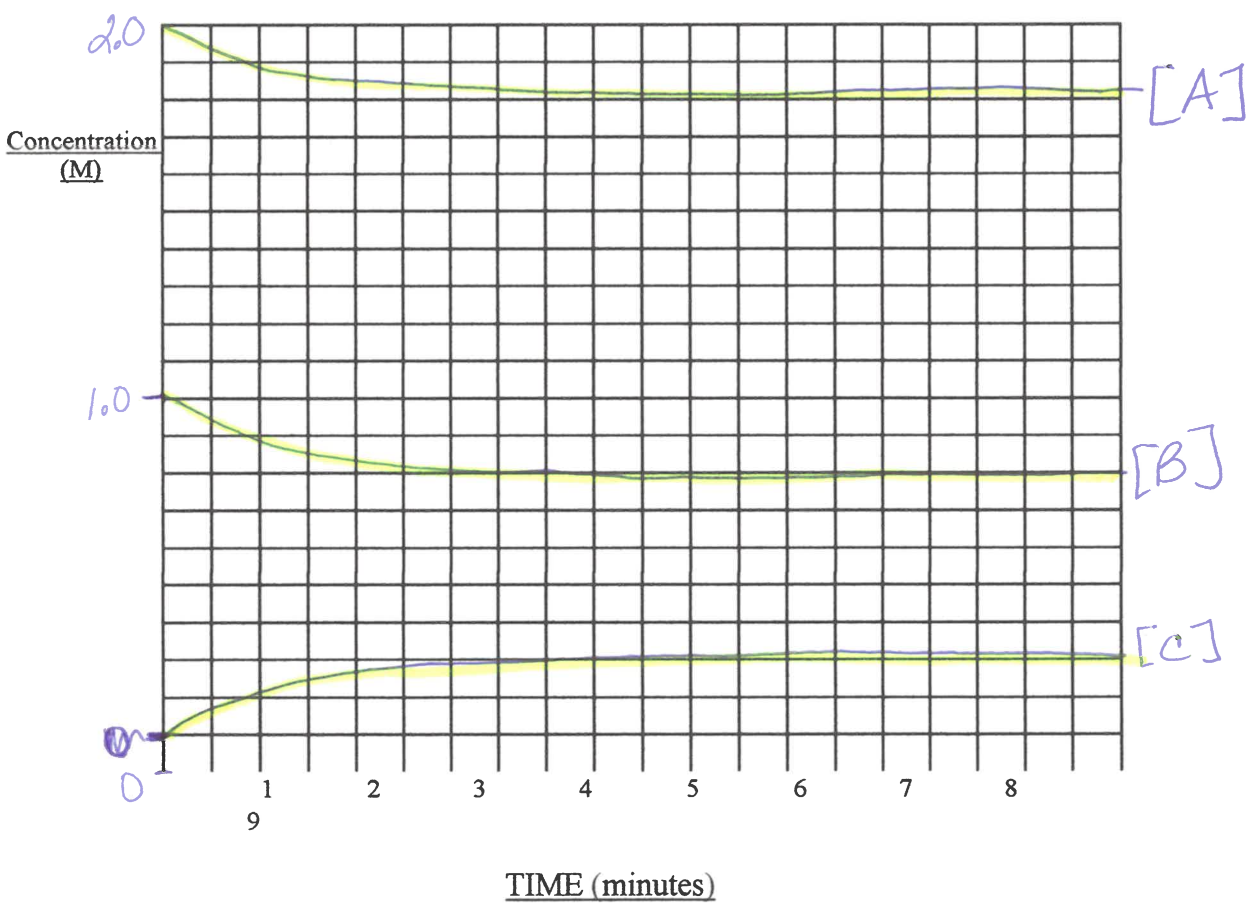
Partial Pressure of A_2 = 20.0 kPa, Partial Pressure of B_2 = 30.0 kPa, Partial Pressure of A_2B_3 = 5.00 kPa.

$$Keq = \frac{[P_{A_2B_3}]^2}{[PA_2]^2[PB_2]^3} = \frac{(5.00)^2}{(20.0)^2(30.0)^3} = 2.31 \times 10^{-6}$$

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.*)

	A +	B ⇌	C
I	1.0 M	2.0 M	0
C	-0.20M	-0.20M	+0.20M
E	0.80M	1.80M	0.20M



25. Given the reaction:

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

How will the value of the equilibrium constant K_{eq} at 550°C compare with it's value at 450°C? Keq @ 550°C will be lower

Explain your answer. ↑T causes shift left to ↓ heat & Keq↓

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

7 mol gas 8 mol gas

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

a) How is the *amount of* N_2 in the container affected if the **volume** of the container is ***doubled***? ↑ in amount of N_2 (shifts right to side w/ more moles of gas)

b) How is the rate of the **forward reaction** affected if more water vapor is introduced into the container? ↑; initial shift left then ↑ fwd rate

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

no change; just speeds up rxn

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

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

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

$$K_{eq} = \frac{[C_6H_6]}{[C_2H_2]^3} \qquad [C_6H_6] = K_{eq}[C_2H_2]^3$$

$$= (5.0)(0.40)^3$$

$$= \boxed{0.32M}$$