.Worksheet 2-3 -- Sec 2.7 and 2.8

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}

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

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

$$K_{eq} = \frac{[0.67]^2}{[5.67][3.45]}$$

Answer 2.3×10^{-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})

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

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

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

Answer 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.

1.0 L container so mol = $\frac{mol}{L}$

	A_2	+ B_2	⇌ $2C$
I	0	0	1.5
C	+0.3	+0.3	−0.6
E	0.3	0.3	0.9

a) What is [A] at equilibrium? Answer 0.3 M

b) What is [B] at equilibrium? Answer 0.3 M

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

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

$$K_{eq} = \frac{[C]^2}{[A][B]}$$

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

$Keq = \frac{0.9^2}{(0.3)(0.3)}$

Answer $Keq = 9$

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

$[AB_3] = \frac{0.87 \text{ mol}}{5 L} = 0.174 M$

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

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.

Answer 1.058 = 1.1 ← sig figs

$Keq = \frac{[C]}{[A][B]} = \frac{0.3}{(0.63)(0.45)}$

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]*.

$1.1 = \frac{0.7}{(0.21)(A)}$

$\frac{0.231A}{0.231} = \frac{0.7}{0.231}$

$A = 3.03$

Answer [A] = 3.03 M

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]*.

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

$1.1 = \frac{(0.86)}{(0.35)B}$

$\frac{0.385B}{0.385} = \frac{0.86}{0.385}$

$B = 2.23$

Answer 2.23 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.

	$2NH_3$	N_2	$3H_2$
I	2.0	0	0
C	-1.0	+0.5	+1.5
E	1.0	+0.5	+1.5

a) What is the equilibrium $[N_2]$? Answer 0.5 M

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

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

$$K_{eq} = \frac{[H_2]^3[N_2]}{[NH_3]^2} = \frac{(1.5)^3(0.5)}{(1.0)^2} = 1.6875$$

Answer K_{eq} = 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	0.5	0	0
C	-0.26	+0.13	+0.13
E	0.24	0.13	0.13

$$K_{eq} = \frac{(0.13)(0.13)}{0.24}$$

Answer K_{eq} = 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:

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

	$2NH_3$	$3H_2$	N_2
I	0.2	0	0.08
C	-0.044	+0.066	+0.022
E	0.156	+0.066	0.102

$[NH_3]_I = \frac{1}{5} = 0.2$

$[N_2]_I = \frac{0.4}{5} = 0.08$

$[NH_3]_E = 0.156$

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

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

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

$$K_{eq} = \frac{(0.102)(0.066)^3}{(0.156)^2}$$

Answer K_{eq} = 0.0012

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

$0.066 \frac{mol}{L} \times 5.0 L = 0.33$

Answer 0.33 mol H_2

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

$0.10 \frac{mol}{L} \times 5 L = 0.5$

Answer 0.5 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. (*Be sure to read all questions a-d before making your table!:*)

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

	PCl_5	PCl_3	Cl_2
I	0.04	0	0
C	-0.025	+0.025	+0.025
E	0.015	0.025	0.025

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.

$K_{eq} = \frac{(0.025)(0.025)}{(0.015)}$

Answer K_{eq} = 0.042

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

$0.025 \frac{mol}{L} \times 10\ L$

Answer 0.25 mol

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

$0.015 \frac{mol}{L} \times 10\ L$

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.

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

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

Answer K_{eq} = 50.

$= 5.0 \times 10^1$ ← sig figs

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?

$50 = \frac{x^2}{(0.05)(0.05)}$

$\sqrt{0.125} = \sqrt{x^2}$

$x = 0.354$

Answer 0.354 M

11. The K_{eq} for the reaction:

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

$K_{eq} = \frac{[Cl_2][PCl_3]}{[PCl_5]}$

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 ?

$0.042 = \frac{(0.049)(x)}{(0.012)}$

$\frac{0.000504}{0.049} = \frac{0.049x}{0.049}$ $x = 0.010$

Answer 0.010 M

12. At a certain temperature the reaction:

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

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

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* $[CH_3OH]$?

$0.500 = \frac{x}{(0.210)(0.1)^2}$

$x = 0.00105$

Answer 1.05×10^{-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*** (< 1 reactants favoured). 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	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

$\sqrt{0.4} = \sqrt{\frac{(0.01-x)^2}{(0.01+x)^2}}$

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

$0.00632 + 0.632x = 0.01 - x$

$-0.00632 \quad +x \quad +x \quad -0.00632$

$1.632x = 0.00368$

$x = 0.0023$

Answer $[CO][H_2O] = 0.0123$ M $[CO_2][H_2] = 0.0077$ 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 $[Y_2]$.

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

	2XY	$\rightleftarrows X_2$	+ Y_2
I	3	0	0
C	−2x	+x	+x
E	3−2x	x	x

$\sqrt{35} = \sqrt{\frac{x^2}{(3-2x)^2}}$

$5.916 = \frac{x}{3-2x}$

$(5.916)(3-2x) = x$

$17.478 - 11.832x = x$

$+11.832x \quad +11.832x$

$\frac{17.478}{12.832} = \frac{12.832x}{12.832}$

$x = 1.36$

Answer $[X_2]$ = 1.4M $[Y_2]$ = 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]?

$[H_2] = \frac{1.0}{0.5} = 2$ $[I_2] = \frac{1.0}{0.5} = 2$

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

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

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

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

$7.07(2-x) = 2x$

$14.14 - 7.07x = 2x$

→ $14.14 - 7.07x = 2x$; $+7.07x$ $+7.07x$

$\frac{14.14}{9.07} = \frac{9.07x}{9.07}$

$1.56 = x$

$[HI] = 2x = 2(1.56) = 3.11$

Answer [HI] = 3.1 M

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

$3.1 \frac{mol}{L} \times 0.5 L = 1.55$

Answer 1.55 mol HI

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?*)

$Q = \frac{[Cl_2][PCl_3]}{[PCl_5]} = \frac{(0.6)(0.6)}{(2.5)}$ $Q = 0.144$

→ Trial Keq > Keq so rxn will shift left so $[PCl_5]$↑ and $[PCl_3]$ and $[Cl_2]$↓

Answer Shift 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?

$Q = \frac{[HI]^2}{[I_2][H_2]} = \frac{(3)^2}{(2)(1.5)} = 3$

Trial Keq < Keq so shift right so [HI]↑ and $[H_2]$ and $[I_2]$↓

Answer Yes   If so, which way does the reaction shift?

Shift right

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!*)

$Q = \frac{[HI]^2}{[H_2][I_2]} = \frac{5^2}{(0.7071)(0.7071)}$

Trial Keq = Keq

Q = 50

Answer No rxn

If so, which way does the reaction shift? it will not

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

$K_{eq} = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.004)^2}{(0.0075)(0.000043)}$

$K_{eq} = 49.6$

Answer $K_{eq} = 50$

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.

$[A]_I = \frac{2.5}{2} = 1.25$ $[B]_I = \frac{0.5}{2} = 0.25$

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

	3A	+ B	⇄ 2C
I	1.25	0.25	0
C	−0.375	−0.125	+0.250
E	0.875	0.125	0.250

Answer [A] = 0.88 M [B] = 0.13 M

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

$K_{eq} = \frac{[C]^2}{[A]^3[B]} = \frac{0.250^2}{(0.875)^3(0.125)}$

Answer 0.75 .

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

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

$CO_{2(g)} + H_{2(g)} \rightleftarrows CO_{(g)} + H_2O_{(g)}$ 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	1.5	1.5	0	0
C	−x	−x	+x	+x
E	1.5−x	1.5−x	x	x

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

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

$0.528(1.5-x) = x$

$0.729 - 0.528x = x$
$+0.528x \quad +0.528x$

$\frac{0.729}{1.528} = \frac{1.528x}{1.528}$

$0.518 = x$

Answer [CO] = 0.518

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?

Trial $K_{eq} = \frac{[C][D]}{[A][B]} = \frac{(1)(1)}{(1)(1)} = 1$

Q > Keq so reaction will shift left to reach Keq.

Answer shift 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.

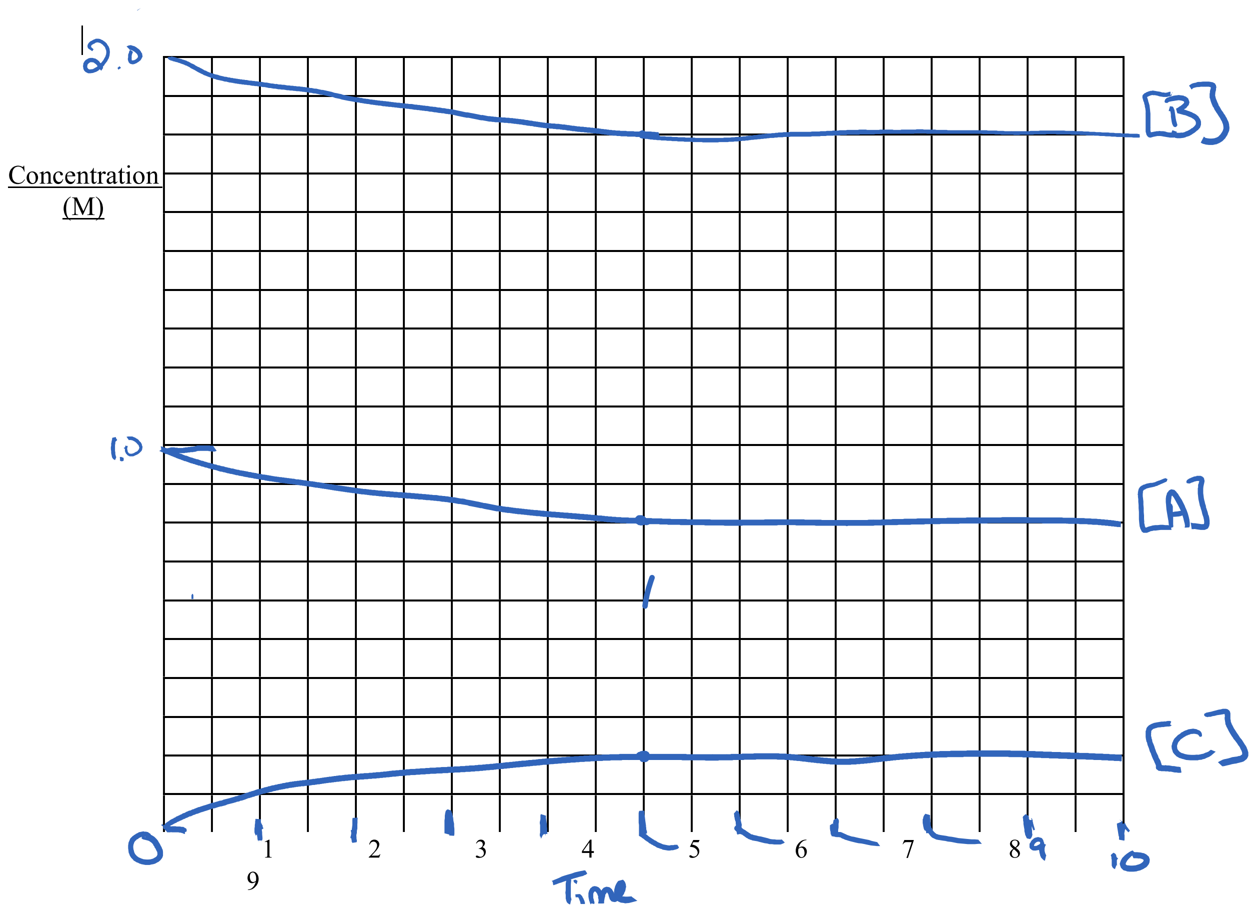
$$K_{eq} = \frac{(P_{A_2B_3})^2}{(P_{A_2})^2(P_{B_2})^3} = \frac{5^2}{(20^2)(30)^3}$$

Answer $K_{eq} = 2.32 \times 10^{-6}$

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	2	0
C	-0.2	-0.2	+0.2
E	0.8	1.8	0.2



TIME (minutes)

25. Given the reaction:

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

How will the value of the equilibrium constant K_{eq} at 550^{o}C compare with it's value at

450^{o}C? Keq will decrease

Explain your answer. Since the rxn is exothermic an increase will shift eq. left ∴ ↑[reactants] making keq ↓

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

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

7 mol 8 mol

a) How is the *amount of* N_2 in the container affected if the ***volume*** of the container is ***doubled***? ↑ Vol = ↓ Pressure ∴ eq shift left - NO2 will ↑

b) How is the rate of the **forward reaction** affected if more water vapor is introduced into the container? rate will increase because rev. rate increases and rates are equal at equilibrium

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

No change as forward & reverse rxns both increase equally.

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

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

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

$$Keq = \frac{(C_6H_6)}{(C_2H_2)^3}$$

$$5 = \frac{x}{0.4^3}$$

$$5 = \frac{x}{0.064}$$

$$0.32 = x$$

Answer [C6H6] = 0.32 mol/L