

(a) $Q_c = \frac{[AB]^2}{[A_2][B_2]} = \frac{(6)^2}{(1)(1)} = 36$

↑
these are numbers of molecules in the picture, rather than molarities, but since ~~there are~~ this is a unitless K_{eq} ($\Delta n_{gas} = 0$) it won't matter.

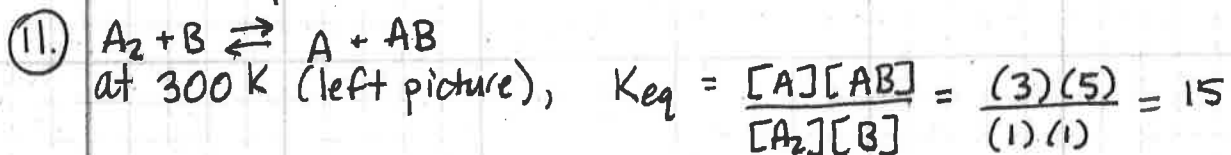
This is not at equilibrium since $Q_c = 36$ but $K_c = 1.5$ ($Q \neq K$). since $Q > K$, the reaction will have to proceed toward reactants / (to the left) / in reverse direction

(b) $Q_c = \frac{3^2}{(3)(2)} = \frac{9}{6} = 1.5$

$Q_c = K_c = 1.5$ so this rxn is at equilibrium.

(c) $Q_c = \frac{2^2}{(3)(3)} = \frac{4}{9} \approx 0.44$

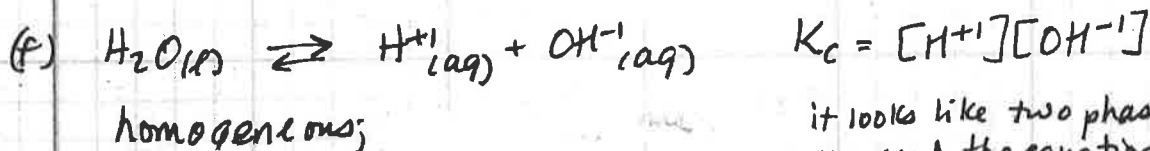
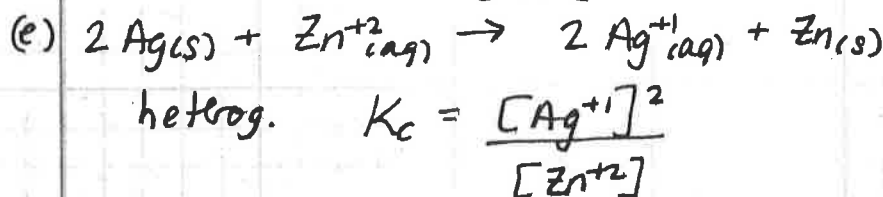
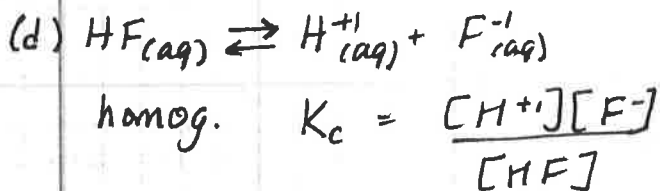
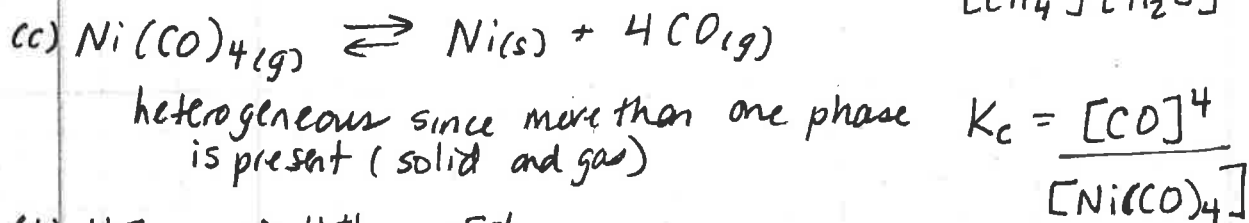
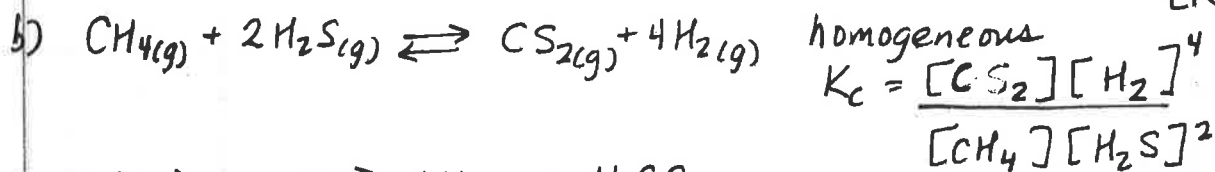
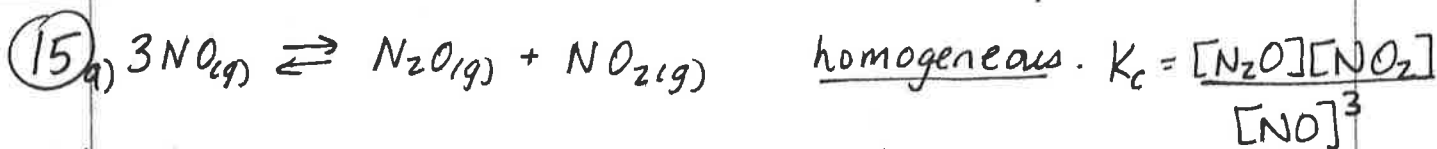
$Q_c < K_c$ so this rxn must proceed toward products / to the right / in the forward direction.



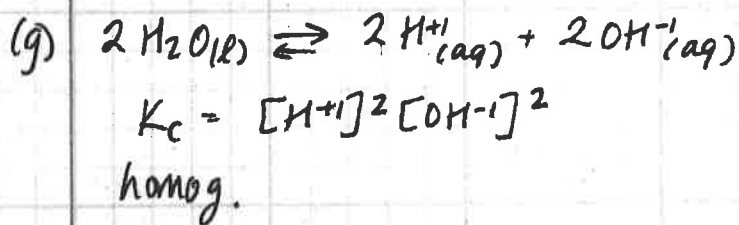
at 500 K (right picture)

$K_{eq} = \frac{[A][AB]}{[A_2][B]} = \frac{(1)(3)}{(3)(3)} = \frac{1}{3} \approx .33..$

$K_{eq} = 15$ @ 300 K
 $K_{eq} = 0.33$ @ 500 K } since K_{eq} decreases as temperature increases, the rxn must be exothermic.



it looks like two phases when you read the equation; (aq) and (l) but ~~the~~ all of the reactants and products are mixed together in one phase.



the mixture

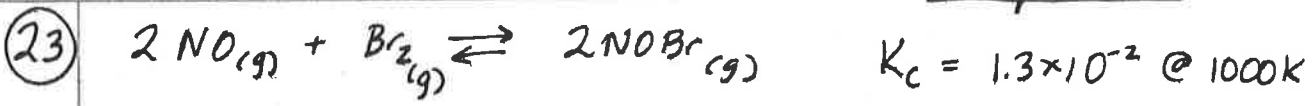
(17) When the rxn reaches equilibrium, will it contain mostly reactants or mostly products?

If $K_{eq} < 1$ then reactants are favored (equilibrium lies to the left) so there will be more reactants.

if $K_{eq} > 1$ then products are favored (eqm lies to right) so there will be more products (eqm lies to right).

a) $K_c = 1.5 \times 10^{-10}$
 $1.5 \times 10^{-10} < 1$ so there will be mostly reactants.

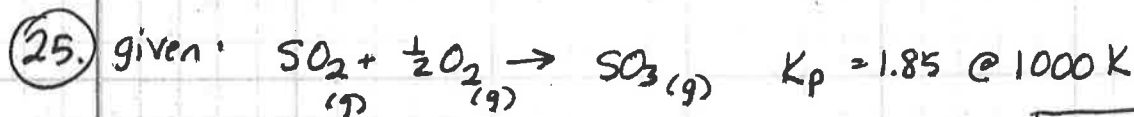
b) $K_p = 2.5 \times 10^9$ so mostly products since $K > 1$



(a) at 1000K, the rxn favors NO and Br₂ (the reactants) (or "equilibrium lies to the left") since $K_c < 1$ (so $\frac{[\text{NOBr}]^2}{[\text{NO}]^2[\text{Br}_2]} = 1.3 \times 10^{-2}$)

(b) calculate K_c for $2 \text{NOBr} \rightleftharpoons 2 \text{NO} + \text{Br}_2$
 this is just the original rxn, except reversed. ($K_c = \frac{[\text{NO}]^2[\text{Br}_2]}{[\text{NOBr}]^2}$)
 $K_{\text{reverse}} = \frac{1}{K_{\text{forward}}} = \frac{1}{1.3 \times 10^{-2}} = 76.92 \rightarrow \boxed{77}$

(c) calculate K_c for $\text{NOBr} \rightleftharpoons \text{NO} + \frac{1}{2} \text{Br}_2$
 this is the original rxn except reversed and divided by 2.
 $K = \left(\frac{1}{1.3 \times 10^{-2}} \right)^{1/2} = 8.7706 \rightarrow \boxed{8.8}$ ($K_c = \frac{[\text{NO}][\text{Br}_2]^{1/2}}{[\text{NOBr}]}$)



(a) find K_p of $\text{SO}_3 \rightarrow \text{SO}_2 + \frac{1}{2} \text{O}_2$ $K_p = \frac{1}{1.85} = \boxed{0.541}$

(b) find K_p of $2 \text{SO}_2 + \text{O}_2 \rightarrow 2 \text{SO}_3$ $K_p = (1.85)^2 = \boxed{3.42}$

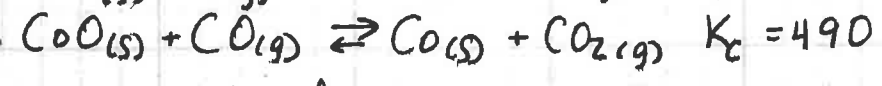
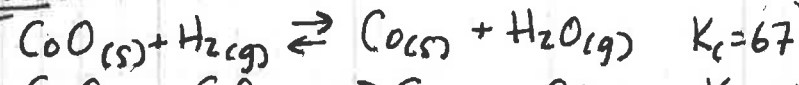
(c) find K_c for the rxn in (b)

$K_p = K_c (RT)^{\Delta n}$ so $K_c = K_p (RT)^{-\Delta n}$

Δn for the rxn in (b) = $2 - 3 = -1$ $K_c = (3.4225) (0.0821 \cdot 1000)^{-(-1)}$

$K_c = \boxed{281}$

27. given:



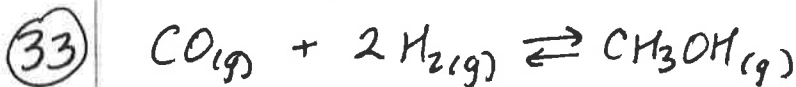
calculate K_c of $\text{H}_2 + \text{CO}_2 \rightleftharpoons \text{CO} + \text{H}_2\text{O}$

leave the first rxn as is: $\text{CoO} + \text{H}_2 \rightleftharpoons \text{Co} + \text{H}_2\text{O}$ $K_c = 67$

reverse the second rxn: $\text{Co} + \text{CO}_2 \rightleftharpoons \text{CoO} + \text{CO}$ $K_c = \left(\frac{1}{490} \right)$

The two rxns now add up to our goal rxn, $\rightarrow \text{H}_2 + \text{CO}_2 \rightleftharpoons \text{CO} + \text{H}_2\text{O}$

so we need to multiply the K_c values together: $K_c = 67 \left(\frac{1}{490} \right) = \boxed{0.14}$.1367



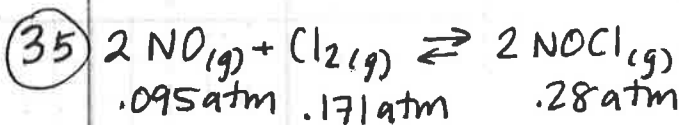
.170 mole .302 mole .0406 mole

← these amounts are present at equilibrium in a 2.00 L vessel. calculate K_c

$$K_c = \frac{[CH_3OH]}{[CO][H_2]^2} = \frac{(\frac{.0406 \text{ mole}}{2.00L})}{(\frac{.170 \text{ mole}}{2.00L})(\frac{.302 \text{ mole}}{2.00L})^2}$$

$$K_c = \frac{.0203 M}{(0.850 M)(.151 M)^2} = 10.474 M^{-2} \rightarrow \boxed{K_c = 10.5}$$

↑ except that all of the molarities are divided by a "reference molarity" of 1.00 M so we get rid of the units...



.095 atm .171 atm .28 atm

← these are the partial pressures @ eqm @ 500.0K. calculate K_p .

(a) $K_p = \frac{P_{NOCl}^2}{P_{NO}^2 \cdot P_{Cl_2}} = \frac{(.28 \text{ atm})^2}{(.095 \text{ atm})^2 (.171 \text{ atm})}$

$$K_p = 50.80106 \text{ atm}^{-1} \rightarrow \boxed{K_p = 51}$$

(again... you divide each pressure by a std pressure of 1 atm and get rid of units...

(b) if $V = 5.00 L$, calculate K_c (still at 500.0K)

{ if you really want to use the 5.00 L, you could use it to solve for moles of each gas ($n = \frac{PV}{RT}$) but then you'd have to divide all your moles by 5.00 L to get molarities for K_c ... so the 5.00 L cancels...

you could do it this way: $P = \frac{nRT}{V} = \frac{n}{V}RT = MRT$

so $M = \frac{P}{RT}$ so $M_{NOCl} = [NOCl] = \frac{.28 \text{ atm}}{(.0821 \frac{L \cdot atm}{mol \cdot K})(500.0K)} = .006821 M$

similarly, $M_{NO} = [NO] = .002314 M$

$M_{Cl_2} = [Cl_2] = .0041656 M$

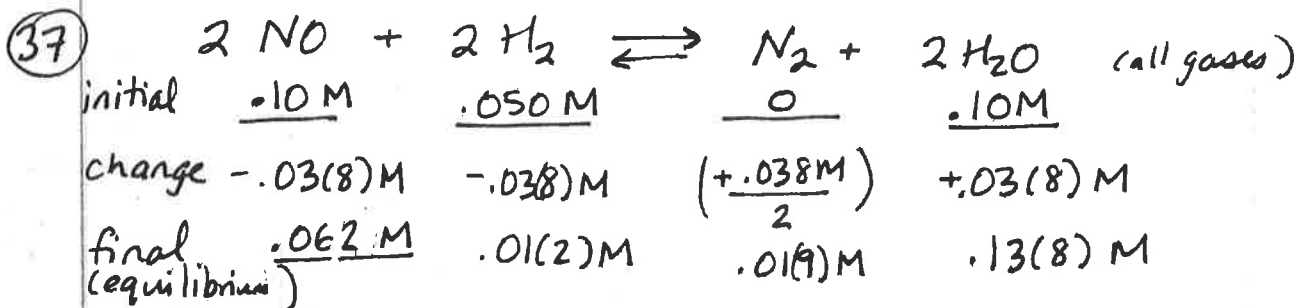
so $K_c = \frac{[NOCl]^2}{[NO]^2 [Cl_2]} = \frac{(.006821)^2}{(.002314)^2 (.0041656)} = 2085.87 \rightarrow \underline{\underline{K_c = 2100}}$

OR (!!! Do this way !!!)

$K_p = K_c (RT)^{\Delta n}$

so $K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{50.80106 \text{ atm}^{-1}}{(.0821 \frac{L \cdot atm}{mol \cdot K})(500K)}^{-1}$

$K_c = 2085.38 \frac{1}{\text{mole}} \rightarrow \boxed{K_c = 2100}$



(a) The underlined values in the above chart were given.

(The "initial" values were actually given as moles but the total volume was 1.0 L, so I changed them to molarities so they would have same units as the given .062 M value. also we'll need molarity values anyway once we calculate K_{eq} .)

.10 M - .062 M = .03(8) M, so NO's molarity was reduced by .038 M. H_2 's molarity has to be reduced by the same amt (acc. to stoichiometry) and H_2O must increase by the same amt (also acc to stoich.)

N_2 ~~also~~ increases half as much as H_2O increases due to the $1/2$ mole ratio.

So eqm molarities:

$[\text{NO}] = .062$
$[\text{H}_2] = .012 \rightarrow .01 \text{ M}$
$[\text{N}_2] = .019 \rightarrow .02 \text{ M}$
$[\text{H}_2\text{O}] = .138 \rightarrow .14 \text{ M}$

(b) $K_c = \frac{[\text{N}_2][\text{H}_2\text{O}]^2}{[\text{NO}]^2[\text{H}_2]^2} = \frac{(.019)(.138)^2}{(.062)^2(.012)^2} = 653.68$

$K_c = 700$

39. Into a 2.000 L vessel at 500 K: .2000 mole CO_2 , .1000 mole H_2 , .1600 mole H_2O

(a) calculate initial partial pressures:

$$P = \frac{nRT}{V} \quad P_{\text{CO}_2} = \frac{(.2000 \text{ mole})(.0821 \frac{\text{L}\cdot\text{atm}}{\text{mole}\cdot\text{K}})(500 \text{ K})}{2.000 \text{ L}} = 4.105 \text{ atm}$$

$$P_{\text{H}_2} = \frac{(.1000)(.0821)(500)}{2.000} \text{ atm} = 2.0525 \text{ atm} \rightarrow \underline{2 \text{ atm}}$$

$$P_{\text{H}_2\text{O}} = \frac{(.1600)(.0821)(500)}{2.000} \text{ atm} = 3.284 \text{ atm} \rightarrow \underline{3 \text{ atm}}$$

4 atm
(or 4.11 if using 500. K)
↑

(b) at eqm, $P_{\text{H}_2\text{O}} = 3.51 \text{ atm}$. calculate p_{CO_2} , P_{H_2} , P_{CO} @ eqm.

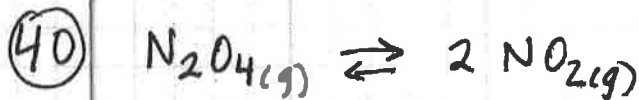
	$\text{CO}_2(g)$	$\text{H}_2(g)$	$\text{CO}(g)$	$\text{H}_2\text{O}(g)$	
Initial	<u>4.105 atm</u>	<u>2.0525 atm</u>	0	<u>3.284 atm</u>	underlined values given/found in (a)
Δ	<u>-0.226</u>	<u>-0.226</u>	<u>+0.226</u>	<u>+0.226</u>	
EQM	<u>3.879</u>		<u>.226</u>	<u>3.51 atm</u>	

$$(c) K_p = \frac{P_{\text{CO}} \cdot P_{\text{H}_2\text{O}}}{P_{\text{CO}_2} \cdot P_{\text{H}_2}} = \frac{(0.226)(3.51)}{(3.879)(1.8265)} = 0.11196 \rightarrow \boxed{0.1 = K_p}$$

$$(d) K_p = K_c(RT)^{\Delta n} \quad K_c = K_p(RT)^{-\Delta n}$$

$$\Delta n_{\text{gas}} = 2 - 2 = 0 \quad \text{so } \boxed{K_p = K_c = 0.1}$$

$$\text{so } K_c = K_p(RT)^0$$



Initial	<u>1.500 atm</u>	<u>1.00 atm</u>
Δ	<u>+0.48(8)</u>	<u>-0.48(8) atm</u>
EQM	<u>1.74(4) atm</u>	<u>0.512 atm</u>

← underlined values were given

(a) $P_{\text{N}_2\text{O}_4} = \boxed{1.74 \text{ atm}}$ at equilibrium

$$(b) K_p = \frac{P_{\text{NO}_2}^2}{P_{\text{N}_2\text{O}_4}} = \frac{(0.512)^2}{(1.744)} = 0.15031 \rightarrow \boxed{0.150 = K_p}$$

$$(c) K_p = K_c(RT)^{\Delta n} \quad K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{.15031}{(.0821)(298)^1} = \boxed{0.00614 = K_c}$$

- 43 (a) how is the reaction quotient (Q) different from the equilibrium constant (K)?

The reaction quotient (Q) is the ratio of product concentrations (or pressures) to reactant concentrations (or pressures) for whatever amounts of reactants and products are in the flask at a particular moment (the rxn may or may not be at equilibrium.)

The equilibrium constant (K) is the ratio of product conc'n/Pressure to reactant conc'n/pressure when at equilibrium.

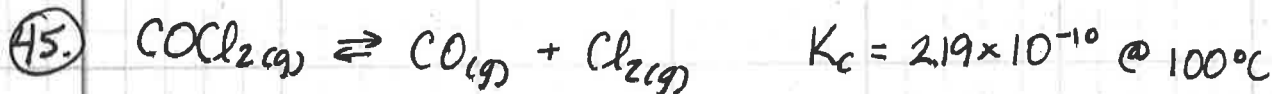
(you must plug in equilibrium pressures or concentrations to evaluate K_{eq} .)

- (b) If $Q < K$, the ratio of products is too low to be at eqm;
reactants

The rxn must proceed in the forward direction (to the right) to reach eqm.

(if $Q > K$, there are too many products per reactants, so reaction must shift left)

- (c) If $Q = K$, the reaction is at equilibrium.



(a) $[\text{COCl}_2] = 2.00 \times 10^{-3} \text{ M}$
 $[\text{CO}] = 3.3 \times 10^{-6} \text{ M}$
 $[\text{Cl}_2] = 6.62 \times 10^{-6} \text{ M}$

$$Q_c = \frac{[\text{CO}][\text{Cl}_2]}{[\text{COCl}_2]} = \frac{(3.3 \times 10^{-6})(6.62 \times 10^{-6})}{(2.00 \times 10^{-3})} = 1.1 \times 10^{-8}$$

(b)

$$Q_c = \frac{(1.1 \times 10^{-9})(2.25 \times 10^{-6})}{(4.50 \times 10^{-2})}$$

$$Q_c = 5.5 \times 10^{-12}$$

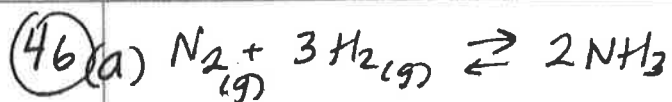
$Q < K$ so must shift right to reach eqm.

$$Q = 1.1 \times 10^{-8}, \quad K = 2.19 \times 10^{-10}$$

$Q > K$ so it is not at eqm.
must shift left to reach eqm.

(c) $Q_c = \frac{(1.48 \times 10^{-6} \text{ M})(1.48 \times 10^{-6} \text{ M})}{(0.0100 \text{ M})} = 2.19 \times 10^{-10}$

$Q = K$ so the rxn is at eqm!

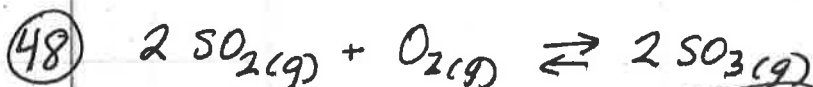


$$K_p = 4.51 \times 10^{-5} @ 450^\circ C$$

which way must it shift if $P_{NH_3} = 98 \text{ atm}$, $P_{N_2} = 45 \text{ atm}$,
 $P_{H_2} = 55 \text{ atm}$?

$$Q_p = \frac{P_{NH_3}^2}{P_{N_2} \cdot P_{H_2}^3} = \frac{(98)^2}{(45)(55)^3} = \underline{1.3 \times 10^{-3}}$$

$Q > K$ so there must shift left
(proceed toward reactants)
to reach eqm.



0.135 atm 0.455 atm

?? atm
at eqm?

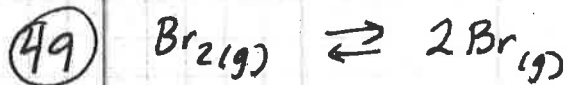
$$K_p = 0.345 @ 900K$$

$$K_p = \frac{P_{SO_3}^2}{P_{SO_2}^2 \cdot P_{O_2}}$$

$$P_{SO_3}^2 = K_p \cdot P_{SO_2}^2 \cdot P_{O_2}$$

$$P_{SO_3}^2 = (0.345)(0.135)^2(0.455) = 0.002861$$

$$P_{SO_3} = (0.002861)^{1/2} = \boxed{0.0535 \text{ atm}}$$



$$K_c = .00104 \text{ at } 1285^\circ C$$

0.245 g
in 0.200 L
vessel
(at eqm)

↑
find mass in
vessel at eqm.

$$K_c = \frac{[Br]^2}{[Br_2]}$$

$$[Br] = (K_c [Br_2])^{1/2}$$

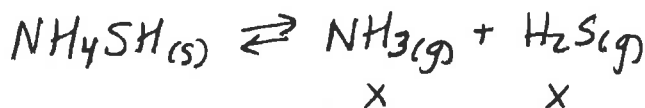
$$[Br_2] = \frac{(0.245 \text{ g}) \left(\frac{1 \text{ mole}}{159.808 \text{ g}} \right)}{0.200 \text{ L}} = 0.0076654 \text{ M}$$

$$\text{so, } [Br] = ((0.00104)(0.0076654))^{1/2}$$

$$[Br] = 0.0028235 \text{ M}$$

$$(0.0028235 \frac{\text{mol}}{\text{L}})(0.200 \text{ L}) \left(\frac{79.904 \text{ g}}{\text{mole}} \right) = \boxed{0.0451 \text{ grams of Br}}$$

54.



$$K_c = 1.2 \times 10^{-4} \text{ at } 218^\circ\text{C}$$

these have to be the same at equilibrium (or at any time) since the flask started out with only solid NH_4SH , and NH_3 and H_2S are 1:1 by stoichiometry.

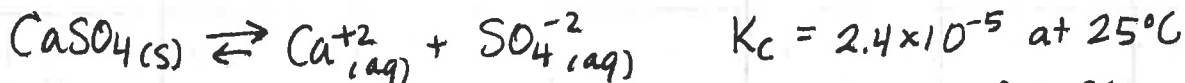
$$K_c = [\text{NH}_3][\text{H}_2\text{S}]$$

$$1.2 \times 10^{-4} = x^2$$

$$x = (1.2 \times 10^{-4})^{1/2} = 0.01095$$

$$\boxed{[\text{NH}_3] = [\text{H}_2\text{S}] = 0.011 \text{ M}}$$

55.



(a) find $[\text{Ca}^{2+}]$ and $[\text{SO}_4^{2-}]$ in a saturated solution of CaSO_4

$$K_c = [\text{Ca}^{2+}][\text{SO}_4^{2-}] = (x)(x) = x^2$$

$$2.4 \times 10^{-5} = x^2$$

$$x = (2.4 \times 10^{-5})^{1/2} = 0.00489898$$

$$\boxed{[\text{Ca}^{2+}] = [\text{SO}_4^{2-}] = 0.0049 \text{ M}}$$

(The calcium and sulfate ions must have same conc'n acc to stoichiometry, since they both started at zero...)

(b) minimum mass of CaSO_4 needed to form a saturated solution with volume of 1.4 L

$$\left(\frac{0.004899 \text{ moles Ca}^{2+}}{\text{L}} \right) \left(\frac{1 \text{ mole CaSO}_4}{1 \text{ mole Ca}^{2+}} \right) (1.4 \text{ L}) \left(\frac{136.1406 \text{ g}}{\text{mole}} \right) = \boxed{0.93 \text{ g CaSO}_4}$$



How will eqm mixture be affected if you:

(a) Add $\text{O}_2(g)$.

This will make the rxn shift right in order to restore the value of K_{eq} ; more SO_3 will be produced, and the SO_2 concentration will decrease

(b) heat up the mixture. (this would increase the temperature...)

This rxn is exothermic, so adding heat will cause the K_{eq} to decrease, so the rxn will shift left; $[\text{SO}_2]$ and $[\text{O}_2]$ will increase, $[\text{SO}_3]$ will decrease.

(c) The volume of the rxn vessel is doubled.

This would cause the pressure of all 3 gases to decrease by a factor of 2, since pressure is inversely prop. to volume. So the rxn will shift left, toward the side with more gas molecules (3 vs 2). so more SO_2 and O_2 will be produced, and SO_3 will be used up/ decrease.

$$K = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]}$$

at eqm. if all molarities decrease by a factor of 2, the numerator will decrease by a factor of $2^2=4$ and denm. will decrease by factor of $2^3=8$. So the value for Q will increase by a factor of 2, so that $Q > K$ and rxn must shift left!

(d) a catalyst is added:
no effect.

(The fwd and reverse rxns will increase by the same factor, but the K_{eq} will remain the same. It is still at eqm)

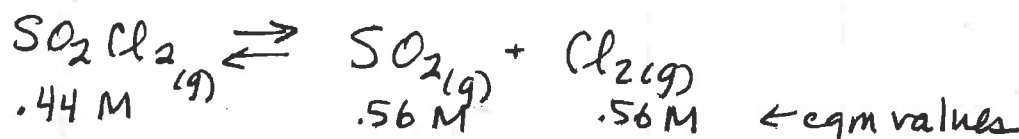
(e) Increase Total pressure by adding a noble gas: no effect. The Noble gas is not involved in K_{eq} , and does not change any partial pressures (or molarities) of SO_3 , SO_2 , or O_2 (and does not affect temperature)

(f) SO_3 is removed: The rxn will need to shift right to make more SO_3 , which will cause SO_2 and O_2 to decrease. (when SO_3 is removed, Q will decrease to below K)

72 (a) 2.00 mole of SO_2Cl_2 in a 2.00 L flask at 303 K.
 56% of SO_2Cl_2 decomposes to SO_2 and Cl_2 .
 Calculate K_c ! $[\text{SO}_2\text{Cl}_2] = \frac{2.00 \text{ mole}}{2.00 \text{ L}} = 1.00 \text{ M}$ at beginning.

$$[\text{SO}_2\text{Cl}_2]_{\text{eqm}} = (1.00 \text{ M}) - (1.00 \text{ M})(0.56) = 0.44 \text{ M}$$

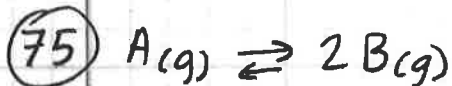
$$\left\{ \begin{aligned} [\text{SO}_2] &= [\text{Cl}_2] = 0.56(1.00 \text{ M}) = 0.56 \text{ M} \end{aligned} \right.$$



$$K_c = \frac{[\text{SO}_2][\text{Cl}_2]}{[\text{SO}_2\text{Cl}_2]} = \frac{(0.56)(0.56)}{(0.44)} = 0.71273 \rightarrow \boxed{0.71}$$

or you could do a table:

	SO_2Cl_2	\rightleftharpoons	SO_2	$+$	Cl_2
Initial	1.00		0		0
Δ	<u>-0.56</u>		<u>+0.56</u>		<u>+0.56</u>
EQM	0.44		0.56		0.56



Initial	<u>0.75</u>	0
Δ	-0.39	+2(0.39)
EQM	<u>0.36</u>	0.78

↑
 these are all partial pressures in atm.

← given pressures (in atm) are underlined

$$P_{\text{TOTAL}} \text{ at eqm} = P_A + P_B$$

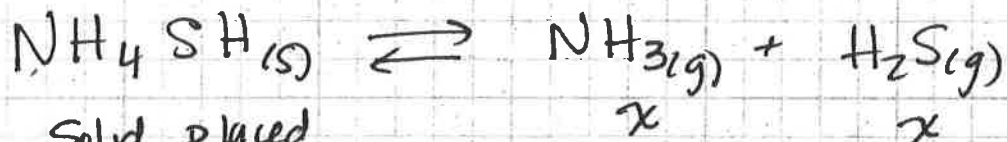
$$P_{\text{TOTAL}} = 0.36 \text{ atm} + 0.78 \text{ atm}$$

(a) $\boxed{P_{\text{TOTAL}} = 1.14 \text{ atm}}$

(b) $K_p = \frac{(P_B)^2}{(P_A)} = \frac{(0.78)^2}{(0.36)} = 1.69 \rightarrow \boxed{1.7 = K_p}$ (b)

Chapter 15

(79)



Solid placed
into evacuated
flask @ 24°C

$P_{\text{TOTAL}} @ \text{EQM} = 0.614 \text{ atm}$
Calculate K_p !

$$P_{\text{NH}_3} = P_{\text{H}_2\text{S}} = x$$

$$\text{Total pressure} = P_{\text{NH}_3} + P_{\text{H}_2\text{S}} = x + x = 2x$$

$$2x = 0.614 \text{ atm}$$

$$x = 0.307 \text{ atm}$$

$$K_p = P_{\text{NH}_3} \cdot P_{\text{H}_2\text{S}} = (0.307)(0.307) = 0.0942$$

$$K_p = 0.0942$$