⑧ $A_2 + B_2 \rightarrow 2\,AB$ $\boxed{K_c = 1.5}$ ← given

(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 ~~these are~~ this is a unitless Keq ($\Delta n_{gas} = 0$) It wont 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.

⑪ $A_2 + B \rightleftarrows A + AB$

at 300 K (left picture), $K_{eq} = \frac{[A][AB]}{[A_2][B]} = \frac{(3)(5)}{(1)(1)} = 15$

at 500 K (right picture)

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

$\left.\begin{array}{l} K_{eq} = 15 \text{ @ } 300\,K \\ K_{eq} = 0.33 \text{ @ } 500\,K \end{array}\right\}$ since Keq decreases as temperature increases, the rxn must be exothermic.

[Chapter 15]

⑮ a) $3NO_{(g)} \rightleftarrows N_2O_{(g)} + NO_{2(g)}$ homogeneous. $K_c = \frac{[N_2O][NO_2]}{[NO]^3}$

b) $CH_{4(g)} + 2H_2S_{(g)} \rightleftarrows CS_{2(g)} + 4H_{2(g)}$ homogeneous

$K_c = \frac{[CS_2][H_2]^4}{[CH_4][H_2S]^2}$

(c) $Ni(CO)_{4(g)} \rightleftarrows Ni_{(s)} + 4CO_{(g)}$

heterogeneous since more than one phase is present (solid and gas) $K_c = \frac{[CO]^4}{[Ni(CO)_4]}$

(d) $HF_{(aq)} \rightleftarrows H^{+1}_{(aq)} + F^{-1}_{(aq)}$

homog. $K_c = \frac{[H^{+1}][F^-]}{[HF]}$

(e) $2Ag_{(s)} + Zn^{+2}_{(aq)} \rightarrow 2Ag^{+1}_{(aq)} + Zn_{(s)}$

heterog. $K_c = \frac{[Ag^{+1}]^2}{[Zn^{+2}]}$

(f) $H_2O_{(l)} \rightleftarrows H^{+1}_{(aq)} + OH^{-1}_{(aq)}$ $K_c = [H^{+1}][OH^{-1}]$

homogeneous;

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

(g) $2H_2O_{(l)} \rightleftarrows 2H^{+1}_{(aq)} + 2OH^{-1}_{(aq)}$

$K_c = [H^{+1}]^2[OH^{-1}]^2$

homog.

⑰ When the rxn reaches equilibrium, will it the mixture 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 left) 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 $K > 1$

㉓ $2NO_{(g)} + Br_{2(g)} \rightleftarrows 2NOBr_{(g)}$ $K_c = 1.3\times10^{-2}$ @ 1000K

(a) at 1000 K, the rxn favors $\boxed{NO \text{ and } Br_2}$ (the reactants)
(or "equilibrium lies to the left")
since $K_c < 1$

$\left(\text{so } \frac{[NOBr]^2}{[NO]^2[Br_2]} = 1.3\times10^{-2}\right)$

(b) calculate K_c for $2NOBr \rightleftarrows 2NO + Br_2$

this is just the original rxn, except reversed. $\left(K_c = \frac{[NO]^2[Br_2]}{[NOBr]^2}\right)$

$$K_{reverse} = \frac{1}{K_{forward}} = \frac{1}{1.3\times10^{-2}} = 76.92 \rightarrow \boxed{77}$$

(c) calculate K_c
for $NOBr \rightleftarrows NO + \frac{1}{2}Br_2$

this is the original rxn except reversed and divided by 2.

$$K = \left(\frac{1}{1.3\times10^{-2}}\right)^{1/2} = 8.7706 \rightarrow \boxed{8.8}$$

$\left(K_c = \frac{[NO][Br_2]^{1/2}}{[NOBr]}\right)$

㉕ given: $SO_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow SO_{3(g)}$ $K_p = 1.85$ @ 1000 K

(a) find K_p of $SO_3 \rightarrow SO_2 + \frac{1}{2}O_2$ $K_p = \frac{1}{1.85} = \boxed{0.541}$

(b) find K_p of $2SO_2 + O_2 \rightarrow 2SO_3$ $K_p = (1.85)^2 = \boxed{3.42}$

(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) $= 2-3 = -1$ $K_c = (3.4225)(.0821\cdot1000)^{-(-1)}$

$\boxed{K_c = 281}$

㉗ given:

$CoO_{(s)} + H_{2(g)} \rightleftarrows Co_{(s)} + H_2O_{(g)}$ $K_c = 67$
$CoO_{(s)} + CO_{(g)} \rightleftarrows Co_{(s)} + CO_{2(g)}$ $K_c = 490$

calculate K_c of $H_{2(g)} + CO_{2(g)} \rightleftarrows CO_{(g)} + H_2O_{(g)}$

leave the first rxn as is: $CoO + H_2 \rightleftarrows Co + H_2O$ $K_c = 67$

reverse the second rxn: $Co + CO_2 \rightleftarrows CoO + CO$ $K_c = \left(\frac{1}{490}\right)$

The two rxns now add up to our goal rxn, $\rightarrow H_2 + CO_2 \rightleftarrows CO + H_2O$

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

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

.170 mole .302 mole .0406 mole ← these amounts are present at equilibrium in a 2.00 L vessel. calculate K_c

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

$$K_c = \frac{.0203\text{ M}}{(0850\text{M})(.151\text{M})^2} = 10.474\text{ M}^{-2} \rightarrow \boxed{K_c = 10.5}$$

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

(35) $2NO_{(g)} + Cl_{2(g)} \rightleftarrows 2NOCl_{(g)}$

.095 atm .171 atm .28 atm ← these are the partial pressures @ eqm @ 500.0 K. 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 500.0 K)

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

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 $$K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{50.80106\text{ atm}^{-1}}{\left[(.0821\frac{l\cdot atm}{mol\cdot K})(500K)\right]^{-1}}$$

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

㊲ $2\,NO + 2\,H_2 \rightleftarrows N_2 + 2\,H_2O$ (all gases)

	$2\,NO$	$2\,H_2$	N_2	$2\,H_2O$
initial	.10 M	.050 M	0	.10M
change	-.03(8)M	-.03(8)M	$\left(+\frac{.038M}{2}\right)$	+.03(8) M
final (equilibrium)	.062 M	.01(2)M	.01(9)M	.13(8) M

(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 Keq.

.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 ~~cha~~ increases half as much as H_2O increases due to the 1/2 mole ratio.

So eqm molarities:

[NO] = .062

$[H_2]$ = .012 → .01 M

$[N_2]$ = .019 → .02 M

$[H_2O]$ = .138 → .14 M

(b) $$K_c = \frac{[N_2][H_2O]^2}{[NO]^2[H_2]^2} = \frac{(.019)(.138)^2}{(.062)^2(.012)^2} = 653.68$$

$$\boxed{K_c = 700}$$

(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:

$$P = \frac{nRT}{V} \qquad P_{CO_2} = \frac{(.2000\text{ mole})(.0821 \frac{\text{l}\cdot\text{atm}}{\text{mol}\cdot\text{k}})(500\text{ K})}{2.000\text{ L}} = 4.105\text{ atm} \to \underline{4\text{ atm}}$$

(or 4.11 if using 500. K!)

$$P_{H_2} = \frac{(.1000)(.0821)(500)}{2.000}\text{ atm} = 2.0525\text{ atm} \to \underline{2\text{ atm}}$$

$$P_{H_2O} = \frac{(0.1600)(.0821)(500)}{2.000}\text{ atm} = 3.284\text{ atm} \to \underline{3\text{ atm}}$$

(b) at eqm, $P_{H_2O} = 3.51$ atm. calculate p_{CO_2}, P_{H_2}, P_{CO} @ eqm.

$$CO_{2(g)} + H_{2(g)} \rightleftarrows CO_{(g)} + H_2O_{(g)}$$

	$CO_{2(g)}$	$H_{2(g)}$	$CO_{(g)}$	$H_2O_{(g)}$
Initial	<u>4.105 atm</u>	<u>2.0525 atm</u>	0	<u>3.284 atm</u>
Δ	−.226	−.226	+.226	+ 0.226
EQM	3.879		.226	<u>3.51 atm</u>

underlined values given/found in (a)

(c) $$K_p = \frac{p_{CO}\cdot p_{H_2O}}{p_{CO_2}\cdot p_{H_2}} = \frac{(0.226)(3.51)}{(3.879)(1.8265)} = 0.11196 \to \boxed{0.1 = K_p}$$

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

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

so $K_c = K_p(RT)^0$

(40) $$N_2O_{4(g)} \rightleftarrows 2\,NO_{2(g)}$$

	$N_2O_{4(g)}$	$2\,NO_{2(g)}$
Initial	<u>1.500 atm</u>	<u>1.00 atm</u>
Δ	$+\left(\frac{.48(8)}{2}\right)$	$-.48(8)$ atm
EQM	1.74(4) atm	<u>0.512 atm</u>

← underlined values were given

(a) $P_{N_2O_4} = \boxed{1.74\text{ atm}}$ at equilibrium

(b) $$K_p = \frac{P_{NO_2}^2}{P_{N_2O_4}} = \frac{(0.512)^2}{(1.744)} = 0.15031 \to \boxed{0.150 = K_p}$$

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

(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/Pressu to reactant conc'n/pressure when at equilibrium.

(you must plug in equilibrium pressures or concentrations to [illegible] evaluate Keq.)

(b) If $Q < K$, the ratio of $\frac{\text{products}}{\text{reactants}}$ is too low to be at eqm;

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.

(45.) $COCl_{2(g)} \rightleftarrows CO_{(g)} + Cl_{2(g)}$ $K_c = 2.19 \times 10^{-10}$ @ 100°C

(a) $[COCl_2] = 2.00 \times 10^{-3}$ M
$[CO] = 3.3 \times 10^{-6}$ M
$[Cl_2] = 6.62 \times 10^{-6}$ M

$$Q_c = \frac{[CO][Cl_2]}{[COCl_2]} = \frac{(3.3\times10^{-6})(6.62\times10^{-6})}{(2.00\times10^{-3})} = 1.1\times10$$

$\boxed{Q = 1.1\times10^{-8}}$, $K = 2.19\times10^{-10}$

$Q > K$ so it is not at eqm.
must shift $\boxed{\text{left}}$ to reach eqm.

(b)
$$Q_c = \frac{(1.1\times10^{-7})(2.25\times10^{-6})}{(4.50\times10^{-2})}$$

$Q_c = 5.5\times10^{-12}$

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

(c) $$Q_c = \frac{(1.48\times10^{-6}\text{ M})(1.48\times10^{-6}\text{ M})}{(0.0100\text{ M})} = 2.19\times10^{-10}$$

$\boxed{Q = K \text{ so the rxn is at eqm!}}$

(46)(a) $N_{2(g)} + 3H_{2(g)} \rightleftarrows 2NH_3$

$K_p = 4.51 \times 10^{-5}$ @ 450°C

which way must it shift if $P_{NH_3} = 98$ atm, $P_{N_2} = 45$ atm, $P_{H_2} = 55$ 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 the rxn must shift <u>left</u> (proceed toward reactants) to reach eqm.

(48) $2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$ $K_p = 0.345$ @ 900K

0.135 atm 0.455 atm ?? atm at eqm?

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

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

$$P_{SO_3}^2 = (.345)(.135)^2(.455) = 0.002861$$

$$P_{SO_3} = (.002861)^{1/2} = \boxed{0.0535 \text{ atm}}$$

(49) $Br_{2(g)} \rightleftarrows 2Br_{(g)}$ $K_c = .00104$ at 1285 °C

0.245 g in 0.200 L vessel (at eqm)

↑ find mass in vessel at eqm.

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

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

$$\text{so, } [Br] = ((.00104)(.0076654))^{1/2}$$

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

$$\left(.0028235 \tfrac{\text{mol}}{\text{L}}\right)(.200\text{L})\left(\frac{79.904\text{g}}{\text{mole}}\right) = \boxed{0.0451 \text{ grams of Br}}$$

54. $NH_4SH_{(s)} \rightleftarrows NH_{3(g)} + H_2S_{(g)}$ $\qquad K_c = 1.2\times10^{-4}$ at 218°C

$\qquad\qquad x \qquad\quad x$

these have to be the <u>same</u> 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.

$K_c = [NH_3][H_2S]$

$1.2\times10^{-4} = x^2$

$x = (1.2\times10^{-4})^{1/2} = 0.01095$

$\boxed{[NH_3] = [H_2S] = .011\ M}$

55. $CaSO_{4(s)} \rightleftarrows Ca^{+2}_{(aq)} + SO_{4\,(aq)}^{-2}$ $\qquad K_c = 2.4\times10^{-5}$ at 25°C

(a) find $[Ca^{+2}]$ and $[SO_4^{-2}]$ in a saturated solution of $CaSO_4$

$K_c = [Ca^{+2}][SO_4^{-2}] = (x)(x) = x^2$

$2.4\times10^{-5} = x^2$

$x = (2.4\times10^{-5})^{1/2} = 0.00489898$

$\boxed{[Ca^{+2}] = [SO_4^{-2}] = .0049\ M}$

(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

$$\left(\frac{.004899 \text{ moles } Ca^{+2}}{L}\right)\left(\frac{1 \text{ mole } CaSO_4}{1 \text{ mole } Ca^{+2}}\right)\left(1.4\ L\right)\left(\frac{136.1406 g}{\text{mole}}\right) = \boxed{0.93 g\ CaSO_4}$$

(61.) $2\,SO_{2(g)} + O_{2(g)} \rightleftarrows 2\,SO_{3(g)}$ $\Delta H < 0$

How will eqm mixture be affected if you:

(a) Add $O_{2(g)}$.

This will make the rxn shift right in order to restore the value of Keq; 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 Keq to decrease, so the rxn will shift left; $[SO_2]$ and $[O_2]$ will increase, $[SO_3]$ 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.

$$\left(K = \frac{[SO_3]^2}{[SO_2]^2[O_2]} \right.$$

at eqm. if all molarities decrease by a factor of 2, the numerator will decrease by a factor of $2^2 = 4$ and denom. 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 Keq 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 Keq, 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 ! $[SO_2Cl_2] = \frac{2.00\text{ mole}}{2.00\text{ L}} = 1.00$ M at beginning.

$$[SO_2Cl_2]_{eqm} = (1.00\text{ M}) - (1.00\text{ M})(.56) = 0.44\text{ M}$$

$$[SO_2] = [Cl_2] = 0.56(1.00\text{ M}) = 0.56\text{ M}$$

$$\underset{.44\text{ M}}{SO_2Cl_{2(g)}} \rightleftarrows \underset{.56\text{ M}}{SO_{2(g)}} + \underset{.56\text{ M}}{Cl_{2(g)}}$$ ← eqm values

$$K_c = \frac{[SO_2][Cl_2]}{[SO_2Cl_2]} = \frac{(.56)(.56)}{(0.44)} = 0.71273 \rightarrow \boxed{0.71}$$

or you could do a table :

	SO_2Cl_2 ⇌	SO_2 +	Cl_2
Initial	1.00	0	0
Δ	−.56	+.56	+0.56
EQM	0.44	0.56	0.56

(75) $A_{(g)} \rightleftarrows 2B_{(g)}$

	$A_{(g)}$	$2B_{(g)}$
Initial	<u>0.75</u>	0
Δ	−0.39	+2(.39)
EQM	<u>0.36</u>	0.78

← given pressures (in atm) are underlined

↗ these are all partial pressures in atm.

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

P_{TOTAL} = 0.36 atm + 0.78 atm

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

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

Chapter 15

(79) $NH_4SH_{(s)} \rightleftarrows NH_{3(g)} + H_2S_{(g)}$

$\qquad\qquad\qquad\qquad\qquad\quad x \qquad\quad x$

Solid placed
into evacuated
flask @ 24°C

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

$p_{NH_3} = p_{H_2S} = x$

Total pressure $= p_{NH_3} + p_{H_2S} = x + x = 2x$

$2x = 0.614$ atm

$x = 0.307$ atm

$K_p = p_{NH_3} \cdot p_{H_2S} = (0.307)(0.307) = 0.0942$

$\boxed{K_p = 0.0942}$