K_p BASICS

PART 1 – Equilibrium quantities

1)	$CH_4(g)$	+	$H_2O(g)$	⇌	$CO(g)$	+	$3\,H_2(g)$
initial moles	3.0		2.0		0		0
changes in moles	**-0.6**		**-0.6**		**+0.6**		**+1.8**
equilibrium moles	**2.4**		**1.4**		0.6		**1.8**

2)	$CH_4(g)$	+	$H_2O(g)$	⇌	$CO(g)$	+	$3\,H_2(g)$
initial moles	0.50		0.20		0		0
changes in moles	**-0.10**		**-0.10**		**+0.10**		**+0.30**
equilibrium moles	**0.40**		**0.10**		**0.10**		0.30

3)	$N_2(g)$	+	$3\,H_2(g)$	⇌	$2\,NH_3(g)$
initial moles	3.0		1.0		0
changes in moles	**-0.15**		**-0.45**		**+0.3**
equilibrium moles	**2.85**		**0.55**		0.3

4)	$N_2(g)$	+	$3\,H_2(g)$	⇌	$2\,NH_3(g)$
initial moles	0.50		0.50		0
changes in moles	**-0.05**		**-0.15**		**+0.10**
equilibrium moles	**0.45**		0.35		**0.10**

5)	$2A(g)$	+	$B(g)$	⇌	$C(g)$	+	$3D(g)$
initial moles	0.40		0.40				
changes in moles	**-0.20**		**-0.10**		**+0.10**		**+0.30**
equilibrium moles	**0.20**		**0.30**		**0.10**		0.30

6)	$2A(g)$	+	$B(g)$	⇌	$C(g)$	+	$3D(g)$
initial moles	0.60		0.20				
changes in moles	**-0.14**		**-0.07**		**+0.07**		**+0.21**
equilibrium moles	**0.46**		**0.13**		0.07		**0.21**

PART 2 – K_p expressions and units

	equilibrium	K_p	units (assume all pressures are in Pa)
1	$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$	$K_p = \frac{(pNH_3)^2}{(pN_2)\,(pH_2)^3}$	**Pa^{-2}**
2	$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$	$K_p = \frac{(pPCl_3)\,(Cpl_2)}{(pPCl_5)}$	**Pa**
3	$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$	$K_p = \frac{(pHI)^2}{(pH_2)\,(pI_2)}$	**No units**
4	$2\,O_3(g) \rightleftharpoons 3\,O_2(g)$	$K_p = \frac{(pO_2)^3}{(pO_3)^2}$	**Pa**
5	$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3\,H_2(g)$	$K_p = \frac{(pCO)\,(pH_2)^3}{(pCH_4)\,(pH_2O)}$	**Pa^2**
6	$CO(g) + 3\,H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$	$K_p = \frac{(pCH_4)\,(pH_2O)}{(pCO)\,(pH_2)^3}$	**Pa^{-2}**
7	$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$	$K_p = \frac{(pSO_3)^2}{(pO_2)\,(pSO_2)^2}$	**Pa^{-1}**
8	$N_2O_4(g) \rightleftharpoons 2\,NO_2(g)$	$K_p = \frac{(pNO_2)^2}{(pN_2O_4)}$	**Pa**

PART 3 – Mole fractions and partial pressures

Mole fraction

If you have 10 moles of a mixture of gases, of which 3 moles is O_2, then the mole fraction of O_2 in the mixture is $\frac{3}{10}$ or 0.3 (or even 30%, but it is not usually expressed as a %)

mole fraction of gas A in a mixture of gases = $\frac{moles\ of\ gas\ A}{total\ moles\ of\ gas\ in\ the\ mixture}$

Note that the sum of all the mole fractions in a mixture should add up to 1

Partial pressure

Imagine a mixture of gases with a total pressure of 100 kPa.

If the mole fraction of gas A in that mixture is $\frac{3}{10}$, then that gas makes up 30 kPa (i.e $\frac{3}{10}$) of the total pressure. The contribution that each gas makes to the total pressure is called the partial pressure of that gas; therefore the partial pressure of gas A is 30 kPa.

partial pressure of gas A = mole fraction of gas A x total pressure
in a mixture of gases

Note that the sum of all the partial pressures is the total pressure.

1)	$CH_4(g)$	+	$H_2O(g)$	⇌	$CO(g)$	+	$3\ H_2(g)$	total pressure = 255 kPa
initial moles	2.00		2.00		0		0	
changes in moles	**-1.20**		**-1.20**		**+1.20**		**+3.60**	
equilibrium moles	**0.80**		**0.80**		**1.20**		3.60	total moles = **6.40**
mole fraction	**0.125**		**0.125**		**0.1875**		**0.5625**	sum of mole fractions = **1.00**
partial pressure	**31.9 kPa**		**31.9 kPa**		**47.8 kPa**		**143.4 kPa**	sum of partial pressures = **255 KPa**

2)	$N_2(g)$	+	$3\ H_2(g)$	⇌	$2\ NH_3(g)$	total pressure = 45.0 MPa
initial moles	0.800		1.000		0	
changes in moles	**-0.200**		**-0.600**		**+0.400**	
equilibrium moles	**0.600**		**0.400**		0.400	total moles = **1.40**
mole fraction	**0.429**		**0.286**		**0.286**	sum of mole fractions = **1.00**
partial pressure	**19.3 MPa**		**12.9 MPa**		**12.9 MPa**	sum of partial pressures = **45 MPa**

3)	$2\ SO_2(g)$	+	$O_2(g)$	⇌	$2\ SO_3(g)$	total pressure = 2.0 MPa
initial moles	5.00		4.00		0	
changes in moles	**-1.50**		**-0.75**		**+1.50**	
equilibrium moles	**3.50**		**3.25**		1.50	total moles = **8.25**
mole fraction	**0.424**		**0.394**		**0.182**	sum of mole fractions =**1.00**
partial pressure	**0.848 MPa**		**0.788 MPa**		**0.364 MPa**	sum of partial pressures = **2.0 MPa**

4)	$H_2(g)$	+	$I_2(g)$	⇌	$2\ HI(g)$	total pressure = P
initial moles	1.50		1.00		0	
changes in moles	**-0.80**		**-0.80**		**+1.60**	
equilibrium moles	**0.70**		**0.20**		1.60	total moles = **2.50**
mole fraction	**0.28**		**0.08**		**0.64**	sum of mole fractions = **1.00**
partial pressure	**0.28P**		**0.08P**		**0.64P**	sum of partial pressures = **P**

PART 4 – K_p problems

Example: Gases A, B and C are in equilibrium. $2\,A(g) + B(g) \rightleftharpoons 2\,C(g)$

a) At equilibrium, there are 2.0 moles of A, 2.5 moles of B and 1.5 moles of C. The total pressure is 500 kPa. Calculate the value of K_p

	$2\,A(g)$ +	**$B(g)$ ⇌**	**$2\,C(g)$**	
equilibrium moles	**2.0**	**2.5**	**1.5**	**total moles = 6.0**
mole fraction	$\frac{2.0}{6.0}$	$\frac{2.5}{6.0}$	$\frac{1.5}{6.0}$	**total of mole fractions = 1**
partial pressures	$\frac{2.0}{6.0}\,x\,500$	$\frac{2.5}{6.0}\,x\,500$	$\frac{1.5}{6.0}\,x\,500$	
partial pressures	**166.7 kPa**	**208.3 kPa**	**125 kPa**	**total of partial pressures = 500 kPa**

$$K_p = \frac{(pC)^2}{(pA)^2\ (pB)} = \frac{(125)^2}{(166.7)^2\ (208.3)} = 0.0027\ \text{kPa}^{-1}$$

b) If the total pressure of this equilibrium was increased, explain what would happen to the yield of C and the value of K_p

equilibrium shifts right
to side with fewer gas molecules
to lower the pressure
so yield of C increases
no change to K_p as it is a constant only affected by temperature

c) The forward reaction is exothermic. If the temperature of this equilibrium was increased, explain what would happen to the yield of C and the value of K_p

equilibrium shifts left
in endothermic direction
to lower the temperature
so yield of C dencreases
K_p decreases