K_p PROBLEMS

1) 1.000 moles of PCl_5 vapour are heated to 500 K in a sealed vessel. The equilibrium mixture, at a pressure of 625 kPa, contains 0.600 moles of chlorine. Calculate K_p.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

	$PCl_5(g)$	$PCl_3(g)$	$Cl_2(g)$	
initial moles	**1.000**			
change	**–0.600**	**+0.600**	**+0.600**	
equilibrium moles	**0.400**	**0.600**	**0.600**	**total moles = 1.600**
mole fraction	$\frac{0.400}{1.600}$	$\frac{0,600}{1.600}$	$\frac{0,600}{1.600}$	**total of mole fractions = 1**
partial pressures	$\frac{1.400}{2.600}\ x\ 625$	$\frac{0.600}{2.600}\ x\ 625$	$\frac{0.600}{2.600}\ x\ 625$	
partial pressures	**156.25 kPa**	**234.375 kPa**	**234.375 kPa**	**total of partial pressures = 500 kPa**

$$K_p = \frac{(pPCl_3)\,(pCl_2)}{(pPCl_5)} = \frac{(234.375)^2}{(156.25)} = \text{352 kPa (3sf)}$$

2) A mixture of 1.90 moles of H_2 and 1.90 moles of I_2 were allowed to reach equilibrium at 710 K. The equilibrium mixture was found to contain 3.00 moles of HI. Calculate K_p.

$$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$$

	$H_2(g)$	$I_2(g)$	$2\,HI(g)$	
initial moles	**1.90**	**1.90**		
change	**–1.50**	**–1.50**	**+3.00**	
equilibrium moles	**0.40**	**0.40**	**3.00**	**total moles = 3.80**
mole fraction	$\frac{0.40}{3.80}$	$\frac{0.40}{3.80}$	$\frac{3.00}{3.80}$	**total of mole fractions = 1**
partial pressures	$\frac{0.40}{3.80}\ x\ P$	$\frac{0.40}{3.80}\ x\ P$	$\frac{3.00}{3.80}\ x\ P$	
partial pressures	**0.1053 P**	**0.1053 P**	**0.7895 P**	**total of partial pressures = 1.00 P**

$$K_p = \frac{(pHI)^2}{(pH_2)\,(pI_2)} = \frac{(0.7895\,P)^2}{(0.1053\,P)^2} = 56$$

3) For the equilibrium below calculate K_p if pO_2 = 102 kPa, pSO_2 = 251 kPa, pSO_3 = 508 kPa.

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$$

$$K_p = \frac{(pSO_3)^2}{(pO_2)\,(pSO_2)^2} = \frac{(508)^2}{(102)\,(251)^2} = 0.0402\ \text{kPa}^{-1}$$

4) 2.00 moles of sulphur dioxide and 1.00 mole of oxygen were mixed and allowed to reach equilibrium in the presence of a suitable catalyst under a total pressure of 500 kPa. At equilibrium, 0.67 moles of oxygen were present. Find K_p.

	$2\,SO_2(g)$ +	$O_2(g)$ ⇌	$2\,SO_3(g)$	
initial moles	**2.00**	**1.00**		
change	**–0.66**	**–0.33**	**+0.66**	
equilibrium moles	**1.34**	**0.67**	**0.66**	**total moles = 2.67**
mole fraction	$\frac{1.34}{2.67}$	$\frac{0.67}{2.67}$	$\frac{0.66}{2.67}$	**total of mole fractions = 1**
partial pressures	$\frac{1.34}{2.67}\,x\,500$	$\frac{0.67}{2.67}\,x\,500$	$\frac{0.66}{2.67}\,x\,500$	
partial pressures	**250.9 kPa**	**125.5 kPa**	**123.6 kPa**	**total of partial pressures = 500 kPa**

$$K_p = \frac{(pSO_3)^2}{(pO_2)\,(pSO_2)^2} = \frac{(123.6)^2}{(125.5)\,(250.9)^2} = 0.00194\ \text{kPa}^{-1}$$

5) 2.00 moles of X was heated to a temperature of 2000°C until equilibrium was established under a total pressure of 80 MPa. At equilibrium, X was found to have undergone 20% dissociation. Calculate K_p.

	$X(g)$ ⇌	$Y(g)$ +	$2\,Z(g)$	
initial moles	**2.00**			
change	**–0.40**	**+0.40**	**+0.80**	
equilibrium moles	**1.60**	**0.40**	**0.80**	**total moles = 2.80**
mole fraction	$\frac{1.60}{2.80}$	$\frac{0.40}{2.80}$	$\frac{0.80}{2.80}$	**total of mole fractions = 1**
partial pressures	$\frac{1.60}{2.80}\,x\,80$	$\frac{0.40}{2.80}\,x\,80$	$\frac{0.80}{2.80}\,x\,80$	
partial pressures	**45.71 MPa**	**11.43 MPa**	**22.86 MPa**	**total of partial pressures = 80 MPa**

$$K_p = \frac{(pY)\,(pZ)^2}{(pX)} = \frac{(11.43)\,(22.86)^2}{(45.71)} = 131\ \text{MPa}^2$$

6) 2.00 moles of A was mixed with 2.00 moles of B and the mixture allowed to reach equilibrium at 500°C. The equilibrium mixture was found to contain 0.90 mole of A. Calculate K_p.

	$2\,A(g)$ +	$B(g)$ ⇌	$3\,C(g)$	
initial moles	**2.00**	**2.00**		
change	**–1.10**	**–0.55**	**+1.65**	
equilibrium moles	**0.90**	**1.45**	**1.65**	**total moles = 4.00**
mole fraction	$\frac{0.90}{4.00}$	$\frac{1.45}{4.00}$	$\frac{1.10}{4.00}$	**total of mole fractions = 1**
partial pressures	$\frac{0.90}{4.00}\,x\,P$	$\frac{1.45}{4.00}\,x\,P$	$\frac{1.10}{4.00}\,x\,P$	
partial pressures	**0.225 P**	**0.3625 P**	**0.4125 P**	**total of partial pressures = P**

$$K_p = \frac{(pC)^3}{(pA)^2\ (pB)} = \frac{(0.4125P)^3}{(0.225P)^2\ (0.3625)} = 3.8$$

7) In the following reaction at 700 K, the amount of each gas present at equilibrium is 0.960 moles of NO_2, 0.040 moles of NO, and 0.020 moles of O_2. If $K_p = 6.80 \times 10^{-4}$ kPa, what must the total pressure have been to achieve this particular equilibrium mixture?

$$2\,NO_2(g) \rightleftharpoons 2\,NO(g) + O_2(g)$$

equilibrium moles	**0.960**	**0.040**	**0.020**	**total moles = 1.020**
mole fraction	$\frac{0.960}{1.020}$	$\frac{0.040}{1.020}$	$\frac{0.020}{1.020}$	**total of mole fractions = 1**
partial pressures	$\frac{0.960}{1.020}\ x\ P$	$\frac{0.040}{1.020}\ x\ P$	$\frac{0.020}{1.020}\ x\ P$	
partial pressures	**0.9412P**	**0.0392P**	**0.0196P**	

$$K_p = \frac{(pO_2)\,(pNO)^2}{(pNO_2)^2}$$

$$6.80\ x\ 10^{-4} = \frac{(0.0196P)\,(0.0392P)^2}{(0.9412P)^2}$$

$$6.80\ x\ 10^{-4} = 3.40\ x\ 10^{-5}\ \ P$$

P = 20 kPa

8) Calculate the number of moles of each species at equilibrium if 0.50 moles of A and 0.50 moles of B are mixed at 500 K, given that $K_p = 2.55$ at this temperature and pressure = P (you do **NOT** need to use a quadratic equation to solve this).

$$A(g) + B(g) \rightleftharpoons 2C(g)$$

initial moles	**0.50**	**0.50**		
change	**–x**	**–x**	**+2x**	
equilibrium moles	**0.50 – x**	**0.50 – x**	**2x**	**total moles = 1.00**
mole fraction	$\frac{0.50-x}{1.00}$	$\frac{0.50-x}{1.00}$	$\frac{2x}{1.00}$	**total of mole fractions = 1**
partial pressures	$\frac{0.50-x}{1.00}\ x\ P$	$\frac{0.50-x}{1.00}\ x\ P$	$\frac{2x}{1.00}\ x\ P$	

$$K_p = \frac{(pC)^2}{(pA^2)\,(pB)} = \frac{\left(\frac{2x}{1.00}\ x\ P\right)^2}{\left(\frac{0.50-x}{1.00}\ x\ P\right)^2} = 2.55$$

Find the square root of both sides: $\dfrac{\left(\frac{2x}{1.00}\ x\ P\right)}{\left(\frac{0.50-x}{1.00}\ x\ P\right)}$ **= 1.60**

$\dfrac{2x}{0.5-x}$ **= 1.60**

$$2x = 1.60(0.5 - x)$$

$$2x = 0.8 - 1.6x$$

$$3.6x = 0.8$$

$$x = 0.222$$