FACTFILE:
GCE CHEMISTRY
4.4 EQUILIBRIUM

Rewarding Learning

Learning Outcomes

Students should be able to:

4.4.1 calculate equilibrium concentrations given suitable data;

4.3.2 calculate the numerical values, with units, for equilibrium constants, K_c, given suitable data limited to homogeneous systems;

The equilibrium constant, K_c

For the equilbrium aA + bB ⇌ cC + dD
The equilibrium constant(Kc) is defined by the expression

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

where [A] represents the concentration of A in mol dm^{-3} in the equilibrium mixture and a is the balancing number for A in the equation for the reaction. The same applies to B, C and D.

To find the units of K_c, simply substitute the units of concentration (mol dm^{-3}) into the Kc expression. Hence the units are in terms of concentration in mol dm^{-3} but the overall power depends on the balancing numbers in the equation for the reaction.

In some cases K_c has no units because there are equal number of moles on both sides of the equation and they **cancel** each other out in the K_c expression.

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

$$\text{Units of } K_c = \frac{(\text{mol dm}^{-3})^{c+d}}{(\text{mol dm}^{-3})^{a+b}}$$

Examples for homogeneous systems

Homogeneous means that all the species are in the same phase.

Equation	K_c	Units
$CH_3CH_2OH + CH_3COOH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$	$K_c = \frac{[CH_3COOCH_2CH_3][H_2O]}{[CH_3COOH][CH_3CH_2OH]}$	$\frac{(mol\ dm^{-3})^2}{(mol\ dm^{-3})^2}$ = no units
$PCl_5 \rightleftharpoons PCl_3 + Cl_2$	$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$	$\frac{(mol\ dm^{-3})^2}{(mol\ dm^{-3})}$ = $mol\ dm^{-3}$
$2HI \rightleftharpoons H_2 + I_2$	$K_c = \frac{[HI]^2}{[H_2][I_2]}$	$\frac{(mol\ dm^{-3})^2}{(mol\ dm^{-3})^2}$ = no units
$2SO_2 + O_2 \rightleftharpoons 2SO_3$	$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$	$\frac{1}{(mol\ dm^{-3})}$ = $mol^{-1}\ dm^3$

The larger the value of K_c the more products will be present in the equbilbrium mixture

Calculating K_c

Example 1

1.33 moles of PCl_5 were heated to 500 K in a vessel of volume 15 dm^3. The equilibrium mixture contained 0.80 mol of chlorine. Calculate a value for K_c.

$PCl_5 \rightleftharpoons PCl_3 + Cl_2$

	PCl_5	PCl_3	Cl_2
Initial moles	1.33	0	0
Change in moles	x moles used	x moles produced	x moles produced
Equilibrium moles	1.33-x	x	x
	At equilibrium there are 0.80 mol of Cl_2 hence x = 0.8		
Equilibrium moles	1.33-0.8 = 0.53	0.8	0.8
Equiblrium concentration (moles/vol dm3)	$\frac{0.53}{15}$ =0.035	$\frac{0.8}{15}$ =0.053	$\frac{0.8}{15}$ =0.053

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{0.053 \times 0.053}{0.035} = 0.080 \text{ mol dm}^{-3}$$

Example 2

A mixture of 1 mol of nitrogen and 3 mol of hydrogen were allowed to come to equilibrium in a container of volume 0.5 dm^3

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

0.240 mol of ammonia were present at equilibrium.
Calculate a value for K_c and state its units.

	N_2	$3H_2$	$2NH_3$
Initial moles	1	3	0
Change in moles (in ratio according tp equation)	x moles used	3x moles used	2x moles produced
Equilibrium moles	1-x	3-3x	2x
	At equibrium there are 0.240 mol of NH_3 0.240 = 2x x = 0.120		
	1-0.120 = 0.880	3 - (3 x 0.120) = 2.640	0.240
Equilibrium concentration (moles/vol dm^3)	$\frac{0.88}{0.5}$ =1.76	$\frac{2.64}{0.5}$ =5.28	$\frac{0.240}{0.5}$ = 0.480

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(0.480)^2}{(1.76)(5.28)^3} = 0.000889 \text{ mol}^{-2}\text{dm}^6$$

Revision Questions

1 1.1 g of pentan-1-ol and 1.2 g of ethanoic acid were mixed. Equilibrium was established at 298K.

$$CH_3COOH + C_5H_{11}OH \rightleftharpoons CH_3COOC_5H_{11}$$

(i) Write an expression for the equilibrium constant, K_c, for this reaction.

[1]

(ii) At equilibrium 0.6 g of ethanoic acid remained. Calculate the value of K_c.

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.... [4]

2 Which one of the following represents the units of K_c for the equilibrium shown below?

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

A mol^{-2} dm^{-6}

B mol^{-2} dm^{6}

C mol^{2} dm^{-6}

D mol^{2} dm^{6}

3 If ammonia (0.2 mol) and methane (0.2 mol) are placed in a 1 dm^3 container and heated to 500°C, it is found that 0.1 mol of hydrogen cyanide and 0.3 mol of hydrogen are produced at one atmosphere pressure. Calculate the equilibrium constant, K_c, for the reaction under these conditions and state its units.

$$NH_3(g) + CH_4(g) \rightleftharpoons HCN(g) + 3H_2(g)$$

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.... [3]

4 1 mol of propanoic acid, 1 mol of methanol and 2 mol of water were mixed and allowed to reach equilibrium.

$$CH_3CH_2COOH + CH_3OH \rightleftharpoons CH_3CH_2COOCH_3 + H_2O$$

At equilibrium 0.5 mol of methyl propanoate was present. The value of K_c for this reaction is

A 1.00

B 1.25

C 5.00

D 10.00