The equilibrium constant

The equilibrium constant, K_c is the ratio of product concentration to reactant concentrations, raised to the appropriate power. This only varies for a reaction when the temperature is changed, and it indicates whether the position of equilibrium is to the left or right. (See module 5 for finding K_c.)

Expression for equilibrium constant

For the reaction $aA + bB \rightleftharpoons cC + dD$

concentration of product (C)

power is the number of moles (of D) in the equation

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

concentration of reactant (A)

power is the number of moles (of B) in the equation

Equilibrium constant for ammonia synthesis

The reaction is $N_2 + 3H_2 \rightleftharpoons 2NH_3$

concentration of ammonia

power is 2; 2 moles of ammonia in the equation

$$K_c = \frac{[NH_3]^2}{[N_2]\,[H_2]^3}$$

concentration of nitrogen

power is 3; 3 moles of hydrogen in the equation

Conditions used in industry

In industry a compromise may be necessary between yield and rate.

1. For an exothermic reaction, a lower temperature gives a higher yield (see page 52).
2. A lower temperature saves energy costs.
3. However, a lower temperature slows down the forward and backward reactions so it would take longer to reach equilibrium.

A compromise temperature will be used.

Estimating the position of equilibrium

- A high value of K_c ($\gg 1$) indicates a position of equilibrium to the right.
- A low value of K_c ($\ll 1$) indicates a position of equilibrium to the left.

K_c for a reaction applies only once the system has reached equilibrium.

Worked example

Nitrogen and hydrogen are mixed in a container and left until equilibrium is reached, according to the equation above.

The equilibrium mixture contained:

$0.127\,\text{mol dm}^{-3}$ hydrogen

$0.0402\,\text{mol dm}^{-3}$ nitrogen

$0.00272\,\text{mol dm}^{-3}$ ammonia.

Calculate K_c. **(3 marks)**

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

$$= \frac{(0.00272\,\text{mol dm}^{-3})^2}{(0.0402\,\text{mol dm}^{-3})\,(0.127\,\text{mol dm}^{-3})^3}$$

$$= \frac{7.3984 \times 10^{-6}\,\text{mol}^2\,\text{dm}^{-6}}{8.2345 \times 10^{-5}\,\text{mol}^4\,\text{dm}^{-12}}$$

$$= 0.0898\,\text{dm}^6\,\text{mol}^{-2}$$

Maths skills For indices, the number on the bottom line is subtracted from the number on the top line:

dm^3: $(-6) - (-12) = -6 + 12 = 6$

mol: $2 - 4 = -2$

Now try this

NO(g), H_2(g), N_2(g) and H_2O(g) exist in equilibrium:

$2NO(g) + 2H_2(g) \rightleftharpoons N_2(g) + 2H_2O(g)$

At room temperature and pressure, the equilibrium lies well to the right hand side.

Which of the following could be the value for the equilibrium constant for this equilibrium? **(1 mark)**

A 1.5×10^{-3} **B** 0.75 **C** 1.0 **D** 6.5×10^2

The equilibrium is well to the right-hand side so $K_c \gg 1$.

For the units, consider the number of moles on each side of the equation. The units can be put into the expression for K_c in an identical way to the concentration values.