Gas equilibria and Kp

AQA 7405 · Full A-level

Show your working where needed. Check the worked answers when you finish.

Name _____ Date _____

1. Write a Kp expression

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$. Write the equilibrium expression for Kp using partial pressures. Deduce its units when every partial pressure is in kPa.

2. Go from amounts to partial pressures

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$. At equilibrium there are 0.600 mol of N_2O_4 and 0.400 mol of NO_2. Total pressure is 150 kPa.

Find both partial pressures and Kp.

3. Two ways to write the Haber equilibrium

At equilibrium $p(N_2)$ = 75.0 kPa, $p(H_2)$ = 145 kPa and $p(NH_3)$ = 90.0 kPa for $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$.

Find Kp and its units for the equation shown and for the equation written to form one mole of NH_3.

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4. A vessel containing phosphorus chlorides

1.20 mol of $PCl_5(g)$ is present initially. At equilibrium for $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, 0.300 mol of PCl_5 has decomposed. Total pressure is 200 kPa.

Calculate Kp at this temperature.

5. Find a missing pressure

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$. Kp = 2.50. At equilibrium, p(CO) = 42.0 kPa, $p(H_2O)$ = 80.0 kPa and $p(H_2)$ = 70.0 kPa.

Find $p(CO_2)$.

6. Change pressure and temperature separately

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$ is endothermic forwards. For each change, predict the equilibrium shift and what happens to Kp.

First consider compression at fixed temperature. Then consider heating the original mixture at fixed total pressure.

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7. Approach the same equilibrium

Two vessels start with identical mixtures of $N_2O_4(g)$ and $NO_2(g)$ at the same pressure and temperature. Only one vessel contains a suitable catalyst.

What changes in the time taken to reach equilibrium, the equilibrium composition and Kp? Explain why.

8. Find the total equilibrium pressure

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$. The equilibrium mole fractions of SO_2, O_2 and SO_3 are 0.250, 0.200 and 0.550 respectively. Kp is 0.242 kPa^{-1}.

Calculate the total pressure.

9. Extra challenge · Infer composition from total pressure

At fixed temperature and volume, a vessel initially contains 0.750 mol PCl_5 and 0.250 mol Ar at 125 kPa. For $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, the total pressure reaches 155 kPa at equilibrium. Argon does not react.

Use the change in total pressure to calculate Kp and give its units. Explain how argon enters the calculation.

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Worked answers

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1. Write a Kp expression

Kp = $p(PCl_3) \times p(Cl_2) \div p(PCl_5)$.

The pressure units give $kPa^2 \div kPa = kPa$.

2. Go from amounts to partial pressures

Total amount is 1.000 mol. Multiply each mole fraction by total pressure: $p(N_2O_4) = 90.0$ kPa and $p(NO_2) = 60.0$ kPa.

Kp = $p(NO_2)^2 \div p(N_2O_4) = 60.0^2 \div 90.0 = 40.0$ kPa.

3. Two ways to write the Haber equilibrium

For the equation shown, Kp = $p(NH_3)^2 \div [p(N_2) \times p(H_2)^3] = 90.0^2 \div (75.0 \times 145^3) = 3.54 \times 10^{-5}$ kPa^{-2}.

Halving all coefficients halves the powers in the expression. The new Kp is $\sqrt{(3.54258\ldots \times 10^{-5})} = 5.95 \times 10^{-3}$ kPa^{-1}. The physical equilibrium is unchanged.

4. A vessel containing phosphorus chlorides

The equilibrium amounts are 0.900 mol PCl_5 and 0.300 mol each of PCl_3 and Cl_2. Total amount is 1.50 mol.

Their partial pressures are 120 kPa, 40.0 kPa and 40.0 kPa. Kp = $40.0 \times 40.0 \div 120 = 13.3$ kPa.

5. Find a missing pressure

Rearrange Kp = $[p(CO_2) \times p(H_2)] \div [p(CO) \times p(H_2O)]$.

$p(CO_2) = 2.50 \times 42.0 \times 80.0 \div 70.0 = 120$ kPa.

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Worked answers

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6. Change pressure and temperature separately

Compression shifts equilibrium towards N_2O_4 because this side has fewer gas molecules. With temperature held fixed, Kp remains constant.

Heating favours the endothermic direction, towards NO_2. Kp increases. Temperature determines the value of Kp for a given balanced equation.

7. Approach the same equilibrium

The catalyst lowers the activation energy for both directions, so equilibrium is reached sooner. It does not affect the equilibrium composition or Kp. Kp for the same equation depends on temperature.

8. Find the total equilibrium pressure

Let total pressure be P. $Kp = p(SO_3)^2 \div [p(SO_2)^2 \times p(O_2)] = (0.550P)^2 \div [(0.250P)^2 \times (0.200P)]$.

One factor of P remains in the denominator, so $P = 0.550^2 \div (0.250^2 \times 0.200 \times 0.242) = 1.00 \times 10^2$ kPa.

9. Extra challenge · Infer composition from total pressure

At constant volume and temperature, total pressure is proportional to total moles. The equilibrium amount is (155/125) × 1.000 = 1.240 mol. Each mole of PCl_5 that decomposes increases the total amount by 1 mol, so 0.240 mol decomposed.

The equilibrium amounts of PCl_5, PCl_3 and Cl_2 are 0.510, 0.240 and 0.240 mol. With the total including Ar, their partial pressures are 63.75, 30.0 and 30.0 kPa. $Kp = 30.0^2/63.75 = 14.1$ kPa. Ar affects the mole fractions and does not appear in the Kp expression.

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