Dynamic equilibrium and Kc

AQA 7404 and 7405 · AS and A level

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

Name _____ Date _____

1. Why equilibrium is dynamic

State the conditions for dynamic equilibrium in a reversible reaction. Explain why the concentrations stay constant.

2. Changing the pressure

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

The gas mixture is compressed at constant temperature. Explain the effect on the equilibrium yield of SO_3.

3. Adding hydrogen

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

Hydrogen is added at constant temperature and volume. Once equilibrium has been restored, how do the HI and I_2 concentrations compare with their original values? Explain.

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4. Equilibrium in a hydrogen iodide mixture

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

Equilibrium concentrations of H_2, I_2 and HI are 0.0150, 0.0120 and 0.0900 mol dm^{-3} respectively. Write the expression for Kc and calculate its value. State whether Kc has units for this equation.

5. Equilibrium in an ammonia mixture

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

At equilibrium, $[N_2] = 0.600$, $[H_2] = 0.400$ and $[NH_3] = 0.720$ mol dm^{-3}. Write the expression for Kc and calculate its value. Give units.

6. What can Kc tell you?

Two equilibria of the form reactant ⇌ product have Kc values of 0.012 and 58. In which mixture is the ratio of product concentration to reactant concentration greater? Can you tell which reaction is faster?

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7. Two equations for one equilibrium

A(aq) + B(aq) ⇌ C(aq) + D(aq). At equilibrium, [A], [B], [C] and [D] are 0.400, 0.200, 0.600 and 0.400 mol dm^{-3} respectively. Calculate Kc for this equation and for C(aq) + D(aq) ⇌ A(aq) + B(aq).

8. Decomposition of phosphorus pentachloride

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$. A 0.800 dm^3 vessel initially contains only 0.1250 mol PCl_5 and 0.0150 mol PCl_3. At equilibrium there is 0.0450 mol Cl_2. Calculate Kc with units.

9. Extra challenge · Use the total amount at equilibrium

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$. A 1.50 dm^3 container initially contains 0.108 mol N_2O_4 and 0.018 mol NO_2. The total amount at equilibrium is 0.163 mol.

Calculate Kc, including units. Then predict the direction of shift and the effect on Kc if the vessel volume is halved at the same temperature.

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Worked answers

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1. Why equilibrium is dynamic

The reaction is in a closed system and both directions continue at the same rate. Each species forms at the same rate as it is used up, so its concentration stays constant.

2. Changing the pressure

The equilibrium shifts right, towards fewer moles of gas. More SO_3 forms as equilibrium is re-established.

3. Adding hydrogen

The added H_2 shifts the equilibrium to the right. It reacts with I_2 to form more HI, so [HI] increases and $[I_2]$ decreases.

4. Equilibrium in a hydrogen iodide mixture

$K_c = [HI]^2 \div ([H_2] \times [I_2]) = 0.0900^2 \div (0.0150 \times 0.0120) = 45.0$.

The concentration powers cancel, so there are no units for this expression. Square brackets denote concentrations.

5. Equilibrium in an ammonia mixture

$K_c = [NH_3]^2 \div ([N_2] \times [H_2]^3) = 0.720^2 \div (0.600 \times 0.400^3) = 13.5$.

The net concentration power is $2 - 4 = -2$, giving $dm^6\ mol^{-2}$.

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Worked answers

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6. What can Kc tell you?

For this equation Kc = [product] ÷ [reactant], so the higher ratio belongs to the equilibrium with Kc = 58.

Kc describes the relative equilibrium concentrations. Reaction rates require kinetic information.

7. Two equations for one equilibrium

For the first equation, Kc = ([C] × [D]) ÷ ([A] × [B]) = (0.600 × 0.400) ÷ (0.400 × 0.200) = 3.00.

For the second equation, Kc = ([A] × [B]) ÷ ([C] × [D]) = (0.400 × 0.200) ÷ (0.600 × 0.400) = 0.333. The two values are reciprocals.

8. Decomposition of phosphorus pentachloride

Forming 0.0450 mol Cl_2 also forms 0.0450 mol PCl_3 and uses 0.0450 mol PCl_5. The final amounts of PCl_5, PCl_3 and Cl_2 are 0.0800, 0.0600 and 0.0450 mol respectively.

$Kc = [PCl_3][Cl_2] \div [PCl_5] = (0.0600 \div 0.800)(0.0450 \div 0.800) \div (0.0800 \div 0.800) = 0.0422$ mol dm^{-3}.

9. Extra challenge · Use the total amount at equilibrium

Each mole of N_2O_4 that dissociates increases total moles by one. The increase is 0.163 − 0.126 = 0.037 mol. At equilibrium there are 0.071 mol N_2O_4 and 0.092 mol NO_2.

$Kc = [NO_2]^2 \div [N_2O_4] = (0.092 \div 1.50)^2 \div (0.071 \div 1.50) = 0.0795$ mol dm^{-3} before final rounding. The net concentration power is one.

Compression shifts equilibrium towards N_2O_4, the side with fewer gaseous molecules. Kc is unchanged because temperature is fixed.

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