Dynamic equilibrium and Kc

OCR A H032 and H432 · 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.

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.

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. Choose operating conditions

The forward reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ is exothermic. Explain how higher pressure affects the equilibrium yield. Explain why an ammonia plant can choose an intermediate temperature instead of the lowest temperature that gives a reaction.

9. Extra challenge · Which reading could follow compression?

For $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, $[N_2O_4] = 0.200$ and $[NO_2] = 0.100$ mol dm^{-3} at equilibrium. The vessel is compressed at constant temperature. At this temperature the equilibrium constant stays the same.

Two teams report new equilibrium concentrations. Team B gives (0.400, 0.200) and team C gives (0.450, 0.150), in the same order and units. Use Kc to decide which team's results could be correct. Explain the change in the proportion of NO_2 molecules.

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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

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

Square brackets denote concentrations.

5. Equilibrium in an ammonia mixture

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

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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. Choose operating conditions

Higher pressure favours the side with fewer gas molecules, so it increases the equilibrium yield of ammonia. A low temperature favours the exothermic forward reaction and gives a higher equilibrium yield, but the reaction is slower. An intermediate temperature gives a useful rate with an acceptable yield.

9. Extra challenge · Which reading could follow compression?

$K_c = [NO_2]^2 \div [N_2O_4]$. The original value is $0.100^2 \div 0.200 = 0.0500$. B gives $0.200^2 \div 0.400 = 0.100$. C gives $0.150^2 \div 0.450 = 0.0500$. C is consistent with Kc remaining constant at fixed temperature.

Compression favours the side with fewer molecules, N_2O_4. The proportion of NO_2 falls from 0.100/(0.200 + 0.100) = ⅓ to 0.150/(0.450 + 0.150) = ¼. Its concentration still rises because the volume is smaller.

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