

Equilibrium constants and shifting equilibria

Chemistry grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer shows the expression, the substitution and the result with units where needed. Check that you used equilibrium (not initial) concentrations, that coefficients became powers, and that your predicted shift agrees with the sign of ΔH and the number of gas moles.

Level: Chemistry grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB R2.3

Problem 1 Equilibrium words

1. A state in which the rate of the forward reaction equals the rate of the reverse reaction, so the concentrations stay constant.
2. **False:** both reactions continue at equal rates.
3. In an open system products or reactants can escape, so equilibrium cannot be established.

Problem 2 Writing Kc

1. $K_c = [\text{NO}]^2 / ([\text{N}_2][\text{O}_2])$; **no units**.
2. $K_c = [\text{N}_2\text{O}_4] / [\text{NO}_2]^2$; **dm³ mol⁻¹**.
3. $K_c = [\text{CO}][\text{H}_2]^3 / ([\text{CH}_4][\text{H}_2\text{O}])$; **mol² dm⁻⁶**.
4. $K_c = [\text{HBr}]^2 / ([\text{H}_2][\text{Br}_2])$; **no units**.

Problem 3 Solids in the expression

1. $K_c = [\text{CO}_2]$; $K_p = p(\text{CO}_2)$.
2. $K_c = [\text{CO}]^2 / [\text{CO}_2]$; $K_p = p(\text{CO})^2 / p(\text{CO}_2)$.
3. The concentration of a pure solid is constant, so it is included in the value of K: **solids are omitted**.

Problem 4 Reading equilibrium concentrations

1. $[\text{NO}] = 0.050$, $[\text{Cl}_2] = 0.040$, $[\text{NOCl}] = 0.200 \text{ mol/dm}^3$.
2. $K_c = [\text{NOCl}]^2 / ([\text{NO}]^2[\text{Cl}_2])$.
3. $K_c = 0.200^2 / (0.050^2 \times 0.040) = 0.0400 / 1.0 \times 10^{-4} = \mathbf{400 \text{ dm}^3 \text{ mol}^{-1}}$.

Problem 5 Size of K

1. **C:** the huge K means products dominate.
2. **A:** the tiny K means almost no products form.
3. B contains comparable amounts of reactants and products.

Problem 6 Predicting the shift

1. **Left** (opposes the added Cl_2).
2. **Left**: 1 mole of gas on the left against 2 on the right.
3. **Right**: the forward reaction is endothermic.
4. **None**.
5. **Right**.

Problem 7 Does K change?

1. **No**: the position shifts but the ratio at equilibrium is the same.
2. **No**: the position shifts only.
3. **Yes**: temperature changes the value of K.
4. **No**: both rates increase equally.

Problem 8 Kp from partial pressures

1. $K_p = p(\text{N}_2\text{O}_4) / p(\text{NO}_2)^2$.
2. $K_p = 30 / 12^2 = 30 / 144 = \mathbf{0.208 \text{ kPa}^{-1}}$.
3. Total = 42 kPa; $x(\text{NO}_2) = 12 / 42 = \mathbf{0.286}$.

Problem 9 Decomposition of PCl_5

1. $[\text{PCl}_5] = 0.060$, $[\text{PCl}_3] = [\text{Cl}_2] = 0.040 \text{ mol/dm}^3$.
2. $K_c = [\text{PCl}_3][\text{Cl}_2] / [\text{PCl}_5]$.
3. $K_c = 0.040^2 / 0.060 = \mathbf{2.67 \times 10^{-2} \text{ mol dm}^{-3}}$.

Problem 10 Reaction quotient

1. $Q = (1.5 \times 1.5) / (0.50 \times 0.50) = 9.0$, which is greater than 6.0, so the mixture shifts **left**.
2. $Q = (0.30 \times 0.30) / (0.20 \times 0.20) = 2.25$, which is less than 6.0, so the mixture shifts **right**.

Problem 11 Finding a concentration

1. $K_c = [\text{H}_2][\text{I}_2] / [\text{HI}]^2$.
2. $[\text{H}_2]^2 = 0.020 \times 0.50^2 = 0.0050$, so $[\text{H}_2] = \mathbf{0.0707 \text{ mol/dm}^3}$.
3. The reverse reaction has the reciprocal constant: $K_c = 1 / 0.020 = \mathbf{50}$ (no units).

Problem 12 Temperature and K

1. K decreases as temperature rises, so the forward reaction is **exothermic**.
2. $8000 / 4.5 = \mathbf{1.8 \times 10^3 \text{ times}}$.
3. A higher temperature shifts the equilibrium in the endothermic (reverse) direction to absorb heat, so less product forms.

Problem 13 Methanol yield

1. Yield **increases** with pressure: there are 3 moles of gas on the left and 1 on the right, so higher pressure favours the side with fewer moles.
2. Yield is lower at 600 K, so the forward reaction is **exothermic (ΔH negative)**.
3. About **58 %** at 500 K and **29 %** at 600 K.

Problem 14 Iron and thiocyanate colours

1. **Deeper red**: extra Fe^{3+} shifts the equilibrium right.
2. **Paler**: removing SCN^- shifts the equilibrium left.
3. **Paler**: all concentrations halve, so $Q = 0.5 / (0.5 \times 0.5) = 2$ times K . Q is greater than K , so the system shifts to the left (the side with more ions).

Problem 15 K_p from mole amounts

1. Total = 1.20 mol: $x(\text{COCl}_2) = 0.50$, $x(\text{CO}) = x(\text{Cl}_2) = 0.25$.
2. $p(\text{COCl}_2) = 75.0 \text{ kPa}$; $p(\text{CO}) = p(\text{Cl}_2) = 37.5 \text{ kPa}$.
3. $K_p = p(\text{CO}) p(\text{Cl}_2) / p(\text{COCl}_2) = 37.5^2 / 75.0 = \mathbf{18.8 \text{ kPa}}$.

Problem 16 K_p from K_c

1. $\Delta n = 2 - 1 = +1$.
2. $RT = 8.314 \times 500 = \mathbf{4157 \text{ kPa dm}^3 \text{ mol}^{-1}}$.
3. $K_p = 0.0267 \times 4157 = \mathbf{111 \text{ kPa}}$.

Problem 17 Esterification

1. $K_c = / ()$.
2. Volume cancels: $x^2 / ((1 - x)(2 - x)) = 4.0$, so $x^2 = 4(2 - 3x + x^2)$, giving $\mathbf{3x^2 - 12x + 8 = 0}$.
3. $x = (12 - \sqrt{48}) / 6 = (12 - 6.928) / 6 = \mathbf{0.845 \text{ mol}}$ (the root 3.15 is impossible).

Problem 18 Water gas shift

1. Initial: 1.00, 1.00, 0, 0. Change: $-x$, $-x$, $+x$, $+x$. Equilibrium: $1 - x$, $1 - x$, x , x .
2. $K_c = x^2 / (1 - x)^2 = 6.0$, so $x / (1 - x) = \sqrt{6} = 2.449$.
3. $x = 2.449 / 3.449 = 0.710 \text{ mol}$; $[\text{H}_2] = 0.710 / 5.0 = \mathbf{0.142 \text{ mol/dm}^3}$.

Problem 19 K at a new temperature

1. $3.3557 \times 10^{-3} - 2.8571 \times 10^{-3} = \mathbf{4.986 \times 10^{-4} \text{ K}^{-1}}$.
2. $\ln(K_2/K_1) = (57200 / 8.314)(4.986 \times 10^{-4}) = 6880 \times 4.986 \times 10^{-4} = \mathbf{3.43}$.
3. $K_2 = 4.6 \times 10^{-3} \times e^{3.43} = 4.6 \times 10^{-3} \times 30.9 = \mathbf{0.142 \text{ mol dm}^{-3}}$; K increases because the forward reaction is endothermic.

Problem 20 Spot the errors

1. Solids are omitted: $K_c = [\text{CO}_2]$.
2. A catalyst does **not change** K_c ; it only speeds up the approach to equilibrium.
3. It shifts towards the side with **fewer** moles of gas.
4. The coefficient becomes a power: $K_c = [\text{B}] / [\text{A}]^2$.