

Equilibrium constants and shifts

AP Chemistry · Worksheet answers

Each answer shows the expression, the substitution and the result in bold. In ICE problems the check step (substituting back into K) is included; do the same in your work. Small differences in the last digit come from rounding intermediate values.

Level: AP Chemistry · **Curriculum:** AP Chem Unit 7

Problem 1 Writing K expressions

1. $K_c = [\text{NH}_3]^2/([\text{N}_2][\text{H}_2]^3)$.
2. $K_c = [\text{CO}_2]$ (solids omitted).
3. $K_c = [\text{SO}_3]^2/([\text{SO}_2]^2[\text{O}_2])$.

Problem 2 What the size of K says

1. 3.0×10^{12} goes almost completely to products.
2. **1.0** has comparable amounts.
3. 2.0×10^{-20} hardly reacts.

Problem 3 Which way does it go?

1. $Q = (0.10)^2/((0.10)^2 \times 0.10) = 0.010/0.0010 = \mathbf{10}$.
2. $Q < K$ ($10 < 25$), so the **forward reaction** runs; more SO_3 forms.

Problem 4 Le Chatelier directions

1. **Right**.
2. **Right**.
3. **Right** (4 mol of gas to 2 mol).
4. **Left** (the reverse is endothermic).
5. **No shift**.

Problem 5 Reading an equilibrium graph

1. About **30 s** (concentrations stop changing).
2. $[\text{A}] = 0.40 \text{ M}$ and $[\text{B}] = 0.60 \text{ M}$.
3. $K = [\text{B}]/[\text{A}] = 0.60/0.40 = \mathbf{1.5}$.
4. **No**; both reactions continue at equal rates.

Problem 6 Changing the equation

1. $1/5.0 = \mathbf{0.20}$.
2. $5.0^2 = \mathbf{25}$.
3. $5.0^{1/2} = \mathbf{2.2}$.

Problem 7 K from measurements

1. $K_c = [\text{HI}]^2/([\text{H}_2][\text{I}_2])$.
2. $K_c = (0.40)^2/(0.050 \times 0.050) = 0.160/0.00250 = \mathbf{64}$.

Problem 8 Kp from Kc

1. $\Delta n = 2 - 1 = \mathbf{+1}$.
2. $K_p = 0.20 \times 0.08206 \times 350 = \mathbf{5.7}$.
3. $1/5.74 = \mathbf{0.17}$.

Problem 9 A perfect-square ICE table

1. H_2 : 0.50, $-x$, $0.50 - x$; I_2 : same; HI : 0, $+2x$, $2x$.
2. $2x/(0.50 - x) = 8$, so $2x = 4.0 - 8x$ and $x = \mathbf{0.40}$.
3. $[\text{H}_2] = [\text{I}_2] = \mathbf{0.10\ M}$; $[\text{HI}] = \mathbf{0.80\ M}$. Check: $0.64/0.010 = 64 \checkmark$.

Problem 10 Finding K from an ICE table

1. CO changes by -0.30 : $[\text{CO}] = \mathbf{0.70\ M}$. H_2 changes by -0.60 : $[\text{H}_2] = \mathbf{1.40\ M}$.
2. $K_c = 0.30/(0.70 \times 1.40^2) = 0.30/1.372 = \mathbf{0.22\ M^{-2}}$.

Problem 11 Starting from a mixture

1. $Q = 0.30^2/0.10 = 0.90 > 0.20$, so the **reverse** reaction runs.
2. NO_2 falls by $2y$, N_2O_4 rises by y : $(0.30 - 2y)^2/(0.10 + y) = 0.20$, so $4y^2 - 1.4y + 0.07 = 0$, $y = 0.0604$. $[\text{NO}_2] = \mathbf{0.18\ M}$, $[\text{N}_2\text{O}_4] = \mathbf{0.16\ M}$. Check: $0.179^2/0.160 = 0.20 \checkmark$.

Problem 12 Temperature and colour

1. The tube turns **darker brown**.
2. The forward reaction is exothermic, so heating makes K **decrease**.
3. After heating, K falls below the old Q ($Q > K$), so the reverse reaction runs and more NO_2 forms.

Problem 13 Compression and Q

1. $K_c = 0.40^2/(0.20^2 \times 0.10) = 0.160/0.0040 = \mathbf{40}$.
2. New concentrations 0.40, 0.20, 0.80 M: $Q = 0.80^2/(0.40^2 \times 0.20) = 0.64/0.032 = \mathbf{20}$.
3. $Q < K$, so the shift is **to the right**, towards 2 mol of gas instead of 3.

Problem 14 A heterogeneous equilibrium

1. $K_p = P(\text{CO})^2/P(\text{CO}_2) = 0.80^2/0.20 = \mathbf{3.2}$.
2. **No effect**; the amount of a pure solid does not appear in K .

3. $Q = 0.64/0.50 = 1.28 < 3.2$, so the shift is **to the right**.

Problem 15 Adding equilibria

1. $N_2 + O_2 + 2 NO + O_2 \rightleftharpoons 2 NO + 2 NO_2$, and cancelling 2 NO gives **$N_2(g) + 2 O_2(g) \rightleftharpoons 2 NO_2(g)$** .

2. $K = K_1 K_2 = 4.0 \times 10^{-31} \times 6.0 \times 10^{12} = 2.4 \times 10^{-18}$.

Problem 16 A quadratic ICE table

1. $x^2/(0.200 - x) = 0.0500$, so $x^2 + 0.0500x - 0.0100 = 0$.

2. $x = [-0.0500 + \sqrt{(0.00250 + 0.0400)}]/2 = 0.0781$.

3. $[PCl_3] = [Cl_2] = 0.078 \text{ M}$; $[PCl_5] = 0.122 \text{ M}$; dissociation = $0.0781/0.200 = 39 \%$.

Problem 17 The small-x approximation

1. $(2x)^2/((0.80 - x)(0.20 - x)) = 1.0 \times 10^{-4}$.

2. With x small: $4x^2 = 1.0 \times 10^{-4} \times 0.16 = 1.6 \times 10^{-5}$, $x = 2.0 \times 10^{-3}$, so $[NO] = 2x = 4.0 \times 10^{-3} \text{ M}$.

3. $x/0.20 = 1.0 \% < 5 \%$: **valid**.

Problem 18 A stress and a new equilibrium

1. $[CO] = 1.333 \text{ M}$; $Q = 0.667^2/(1.333 \times 0.333) = 1.0$.

2. $Q < K$ ($1.0 < 4.0$), so the shift is **forward**.

3. $(0.667 + y)^2/((1.333 - y)(0.333 - y)) = 4.0$ gives $3y^2 - 8y + 1.333 = 0$, $y = 0.179$. $[CO_2] = [H_2] = 0.845 \text{ M}$, $[CO] = 1.155 \text{ M}$, $[H_2O] = 0.155 \text{ M}$.

Problem 19 Deducing ΔH from K

1. K falls as T rises, so the forward reaction is exothermic: **$\Delta H < 0$** .

2. The yield **decreases**.

3. Higher pressure favours the side with fewer gas moles: the yield **increases**.

4. A catalyst does not change K but lets the reaction reach equilibrium quickly at a moderate temperature.

Problem 20 Cobalt chloride equilibrium

1. $K_c = [CoCl_4^{2-}]/([Co(H_2O)_6^{2+}][Cl^-]^4)$ (water omitted).

2. HCl: **blue** (more Cl^- , shift right). Water: **pink** (dilution shifts left). Heating: **blue** (endothermic direction, K rises).

3. $Q = 0.0020/(0.010 \times 0.50^4) = 0.0020/(6.25 \times 10^{-4}) = 3.2 < 5.0$, so the shift is **forward** (more blue).