

Equilibrium constants and shifting equilibria

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

Name: _____ Date: _____ Class: _____

These 20 problems cover writing and calculating K_c and K_p , ICE tables, the reaction quotient, and predicting shifts from concentration, pressure and temperature changes. They begin with expressions and qualitative shifts and finish with quadratic equilibria and the effect of temperature on K .

The level suits IB Chemistry, A Level, CBSE Class 11-12 and WAEC/NECO senior students. Always write the expression first and check the units.

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

Problem 1 Equilibrium words (easy)

Aarav in Pune is revising.

1. Define dynamic equilibrium.
2. State whether this is true or false and correct it if false: at equilibrium the reaction has stopped.
3. State why a closed system is needed.

Problem 2 Writing K_c (easy)

Write the K_c expression and the units of K_c for each.

1. $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$
2. $2NO_2(g) \rightleftharpoons N_2O_4(g)$
3. $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$
4. $H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$

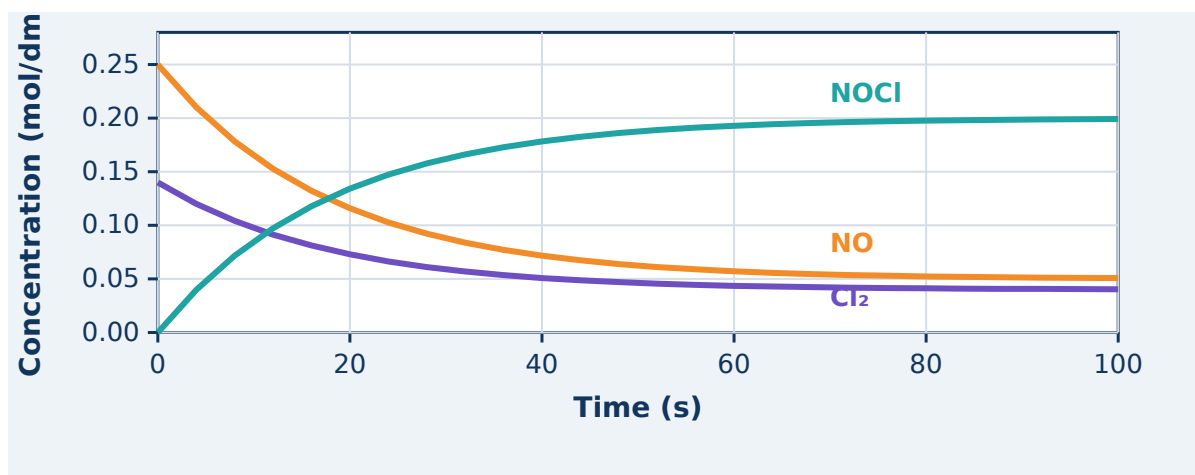
Problem 3 Solids in the expression (easy)

Write K_c and K_p for each equilibrium.

1. $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
2. $C(s) + CO_2(g) \rightleftharpoons 2CO(g)$
3. Explain why solids do not appear.

Problem 4 Reading equilibrium concentrations (easy)

The graph shows $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ approaching equilibrium.



Reaction of NO with Cl₂ to form NOCl.

1. Read the equilibrium concentrations.
2. Write the K_c expression.
3. Calculate K_c with units.

Problem 5 Size of K (easy)

Chiamaka in Lagos compares three reactions at 298 K: (A) $K = 2 \times 10^{-25}$, (B) $K = 1.0$, (C) $K = 6 \times 10^{30}$.

1. State which reaction gives mostly products at equilibrium.
2. State which gives mostly reactants.
3. State what the mixture in B looks like.

Problem 6 Predicting the shift (easy)

$\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$ has $\Delta H = +93 \text{ kJ/mol}$. State the shift (left, right or none) for each change.

1. Chlorine is added.
2. The pressure is increased by compression.
3. The temperature is raised.
4. A catalyst is added.
5. PCl_3 is removed as it forms.

Problem 7 Does K change? (medium)

Wanjiru in Nairobi studies an equilibrium. State whether K_c changes for each action and give a reason.

1. Adding more reactant
2. Compressing the gas mixture
3. Raising the temperature
4. Adding a catalyst

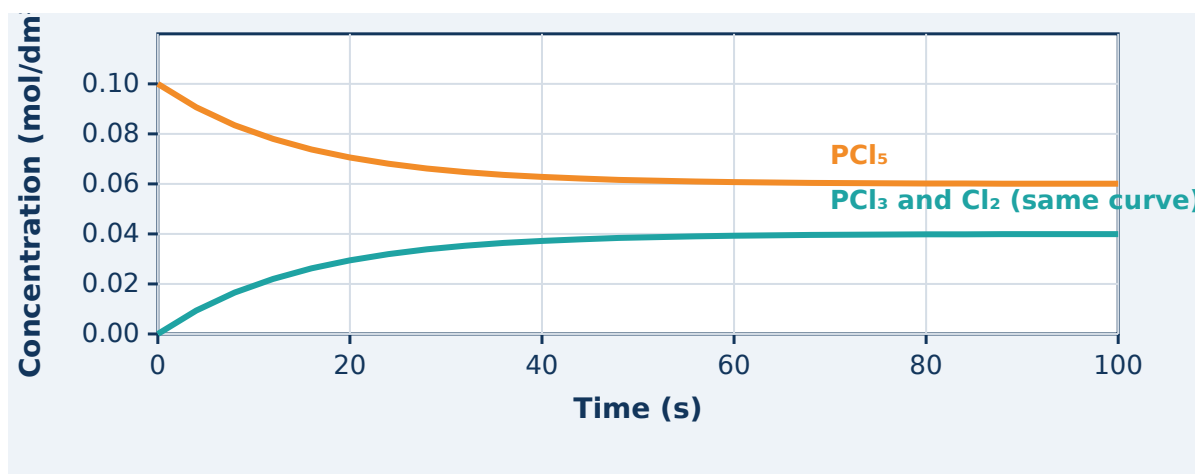
Problem 8 Kp from partial pressures (medium)

In $2\text{NO}_2(\text{g}) \rightleftharpoons \text{N}_2\text{O}_4(\text{g})$ the equilibrium partial pressures are $p(\text{N}_2\text{O}_4) = 30 \text{ kPa}$ and $p(\text{NO}_2) = 12 \text{ kPa}$.

1. Write the Kp expression.
2. Calculate Kp with units.
3. Calculate the total pressure and the mole fraction of NO_2 .

Problem 9 Decomposition of PCl_5 (medium)

The graph shows 0.100 mol/dm^3 of PCl_5 decomposing in a closed vessel.



Decomposition of PCl_5 in a closed vessel.

1. Read the equilibrium concentrations.
2. Write the Kc expression.
3. Calculate Kc with units.

Problem 10 Reaction quotient (medium)

$\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + \text{H}_2(\text{g})$ has $K_c = 6.0$ at a certain temperature.

1. Mixture 1: $[\text{CO}] = [\text{H}_2\text{O}] = 0.50$, $[\text{CO}_2] = [\text{H}_2] = 1.5 \text{ mol/dm}^3$. Calculate Q and state the direction of change.
2. Mixture 2: $[\text{CO}] = [\text{H}_2\text{O}] = 0.20$, $[\text{CO}_2] = [\text{H}_2] = 0.30 \text{ mol/dm}^3$. Calculate Q and state the direction of change.

Problem 11 Finding a concentration (medium)

For $2\text{HI}(\text{g}) \rightleftharpoons \text{H}_2(\text{g}) + \text{I}_2(\text{g})$, $K_c = 0.020$ at a given temperature. At equilibrium $[\text{HI}] = 0.50 \text{ mol/dm}^3$ and $[\text{H}_2] = [\text{I}_2]$.

1. Write the Kc expression.
2. Calculate $[\text{H}_2]$.
3. Calculate Kc for the reverse reaction $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$ at the same temperature.

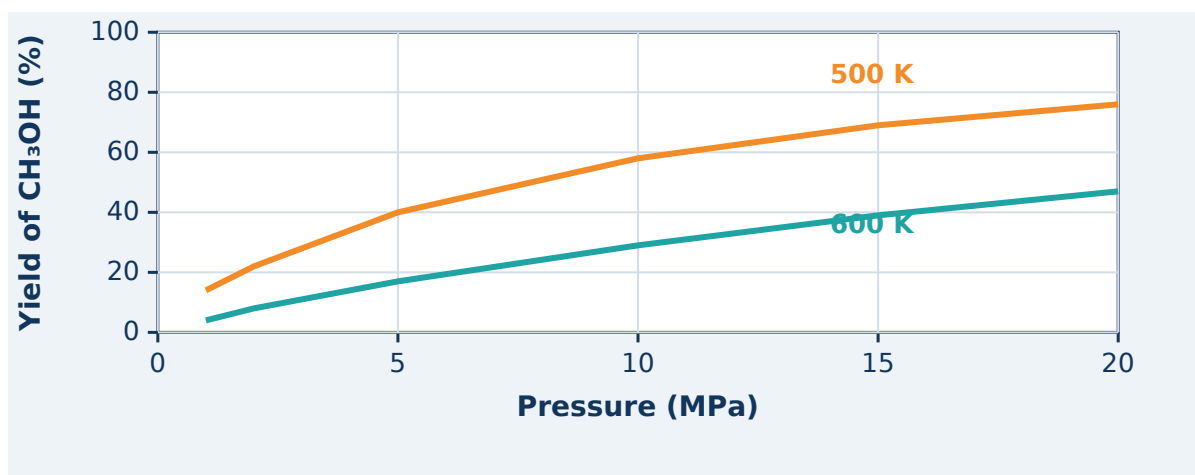
Problem 12 Temperature and K (medium)

For a reaction X the equilibrium constant is 8.0×10^3 at 300 K, 1.2×10^2 at 400 K and 4.5 at 500 K.

1. Deduce whether the forward reaction is exothermic or endothermic.
2. Calculate how many times K falls from 300 K to 500 K.
3. Explain, in terms of Le Chatelier's principle, why the yield falls as the temperature rises.

Problem 13 Methanol yield (medium)

The graph shows the equilibrium yield of methanol from $\text{CO(g)} + 2\text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)}$ at 500 K and 600 K.



Equilibrium yield of CH_3OH at two temperatures.

1. State and explain the effect of pressure on the yield.
2. State the effect of temperature and deduce the sign of ΔH .
3. Read the yield at 10 MPa for each temperature.

Problem 14 Iron and thiocyanate colours (medium)

$\text{Fe}^{3+}(\text{aq})$ (pale yellow) + $\text{SCN}^{-}(\text{aq})$ (colourless) $\rightleftharpoons [\text{Fe}(\text{SCN})]^{2+}(\text{aq})$ (red). Predict the colour change and explain it for:

1. adding more iron(III) nitrate solution
2. adding silver nitrate, which removes SCN^{-} as a precipitate of AgSCN
3. adding an equal volume of water

Problem 15 Kp from mole amounts (medium)

At 150 kPa total pressure, an equilibrium mixture of $\text{COCl}_2(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + \text{Cl}_2(\text{g})$ contains 0.60 mol COCl_2 , 0.30 mol CO and 0.30 mol Cl_2 .

1. Calculate the mole fraction of each gas.
2. Calculate the partial pressures.
3. Calculate K_p with units.

Problem 16 Kp from Kc (hard)

For $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$, $K_c = 0.0267 \text{ mol/dm}^3$ at 500 K. Use $K_p = K_c(RT)^{\Delta n}$ with $R = 8.314 \text{ kPa dm}^3 \text{ mol}^{-1} \text{ K}^{-1}$.

1. State Δn , the change in moles of gas.
2. Calculate RT .
3. Calculate K_p with units.

Problem 17 Esterification (hard)

Emma in Leeds mixes 2.00 mol of ethanol with 1.00 mol of ethanoic acid. $\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}$ has $K_c = 4.0$ (no units).

1. Write the K_c expression.
2. Let x be the moles of ester formed. Show that $3x^2 - 12x + 8 = 0$.
3. Calculate the moles of ester at equilibrium.

Problem 18 Water gas shift (hard)

Diego in Texas mixes 1.00 mol CO and 1.00 mol $\text{H}_2\text{O}(\text{g})$ in a 5.0 dm^3 vessel. $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$ has $K_c = 6.0$.

1. Draw an ICE table in moles (let x mol react).
2. Show that $x / (1 - x) = \sqrt{6}$.
3. Calculate the equilibrium concentration of H_2 .

Problem 19 K at a new temperature (hard)

$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ has $\Delta H = +57.2 \text{ kJ/mol}$ and $K_c = 4.6 \times 10^{-3} \text{ mol/dm}^3$ at 298 K. Use $\ln(K_2/K_1) = (-\Delta H/R)(1/T_2 - 1/T_1)$.

1. Calculate $1/298 - 1/350$.
2. Calculate $\ln(K_2/K_1)$ for 350 K.
3. Calculate K_c at 350 K and state the direction of the change.

Problem 20 Spot the errors (hard)

Find and correct the error in each statement.

1. For $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$, $K_c = [\text{CaO}][\text{CO}_2] / [\text{CaCO}_3]$.
2. Adding a catalyst increases the value of K_c .
3. Increasing the pressure shifts the equilibrium towards the side with more moles of gas.
4. For $2\text{A} \rightleftharpoons \text{B}$, $K_c = [\text{B}] / 2[\text{A}]$.