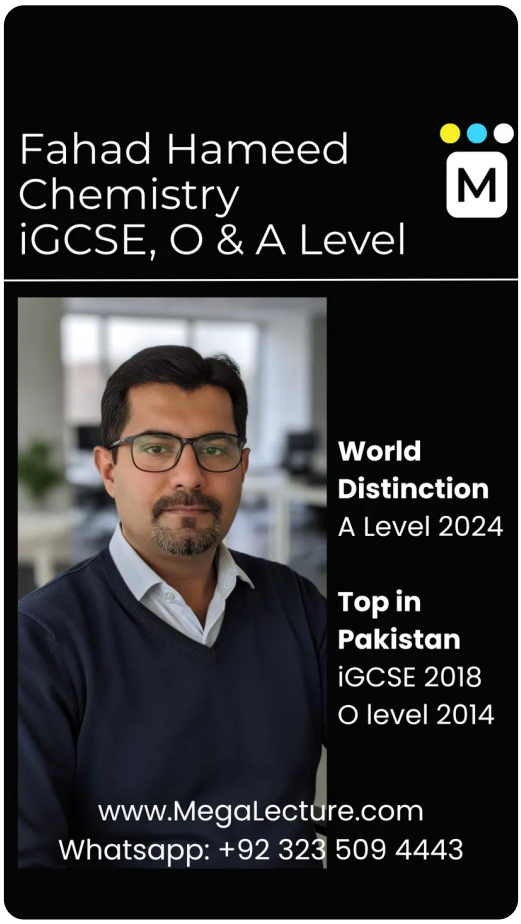
MEGA LECTURE · A LEVEL CHEMISTRY

Chapter 20: The Equilibrium Constant K_p

OCR A Level Chemistry A (H432) — Structured Practice Worksheet



SPECIFICATION	TOTAL MARKS	SUGGESTED TIME
3.3.2 Equilibrium constant K_p: mole fraction, partial pressure, K_p expressions and calculations	76	1 hour 30 minutes

www.MegaLecture.com · WhatsApp: +92 323 509 4443

MEGA LECTURE · A LEVEL CHEMISTRY

Chapter 20: The Equilibrium Constant K_p

OCR A Level Chemistry A (H432) — Structured Practice Worksheet

SPECIFICATION	TOTAL MARKS	SUGGESTED TIME
3.3.2 Equilibrium constant K_p: mole fraction, partial pressure, K_p expressions and calculations	76	1 hour 30 minutes

Instructions to candidates

- Answer **all** questions in the spaces provided. Show all working in calculations.
- Marks are shown in brackets [ ] at the end of each part.

Question 1 — Mole fraction and partial pressure

3.3.2

a. Define the term *mole fraction* of a gas in a mixture. **[1]**

b. Define the term *partial pressure* of a gas, and state the equation linking it to mole fraction and total pressure. **[2]**

c. A gas mixture at a total pressure of 100 kPa contains 2.00 mol N_2, 6.00 mol H_2 and 4.00 mol NH_3. Calculate the mole fraction and partial pressure of each gas. **[5]**

d. A different gas mixture at a total pressure of 300 kPa contains only gases X and Y, present in equal mole fractions. Calculate the partial pressure of each gas. **[2]**

Question 1 total: 10 marks

Question 2 — Writing Kp expressions

3.3.2

a. Write the expression for K_p, including units, for each of the following gaseous equilibria (assume all partial pressures are measured in kPa). **[12]**

Equilibrium	K_p expression (with units)
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$	
$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$	
$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$	

Question 2 total: 12 marks

Question 3 — Calculating Kp from an equilibrium mixture (1) 3.3.2

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$. At a certain temperature, an equilibrium mixture at a total pressure of 200 kPa contains 0.60 mol N_2O_4 and 1.40 mol NO_2.

a. Calculate the total number of moles of gas present, and the mole fraction of each gas. **[3]**

b. Calculate the partial pressure of each gas. **[2]**

c. Write the expression for K_p and calculate its value, including units. **[4]**

d. At the same temperature, a different equilibrium mixture has a partial pressure of N_2O_4 of 80.0 kPa. Using your value of K_p from (c), calculate the partial pressure of NO_2 in this mixture. **[3]**

Question 3 total: 12 marks

Question 4 — Calculating Kp from an equilibrium mixture (2) 3.3.2

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$. 2.00 mol of $PCl_5(g)$ is placed in a container and allowed to reach equilibrium at a total pressure of 150 kPa. At equilibrium, the PCl_5 is 40.0% dissociated.

a. **[4]**

Using an initial/change/equilibrium table, determine the equilibrium amount, in mol, of PCl_5, PCl_3 and Cl_2.

b. Calculate the total number of moles of gas at equilibrium and the mole fraction of each gas. **[3]**

c. Calculate the partial pressure of each gas. **[3]**

d. Write the expression for K_p and calculate its value, including units. **[3]**

e. The forward (decomposition) reaction is endothermic. Predict, with a reason, how the value of K_p would change if the temperature were increased. **[2]**

Question 4 total: 15 marks

Question 5 — Pressure and the equilibrium constant 3.3.2

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

a. State the effect of increasing the total pressure, at constant temperature, on the value of K_p. **[1]**

b. Explain why K_p is unaffected by a change in pressure, even though the position of equilibrium may shift. **[3]**

c. Explain what happens to the position of equilibrium when the pressure on this system is increased, and state whether the value of K_p changes as a result. **[3]**

Question 5 total: 7 marks

Question 6 — Temperature and the equilibrium constant 3.3.2

a. For an exothermic forward reaction, state whether K_p increases or decreases as temperature increases. **[1]**

b. Explain, in terms of Le Chatelier's principle and the K_p expression, why K_p changes in this way for an exothermic reaction as temperature increases. **[3]**

c. For an endothermic forward reaction, state and explain the effect of increasing temperature on K_p. **[2]**

Question 6 total: 6 marks

Question 7 — Heterogeneous equilibria 3.3.2

$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

a. Explain why the pure solids $CaCO_3$ and CaO are omitted from the K_p expression for this equilibrium. **[2]**

b. Write the expression for K_p for this equilibrium. **[2]**

c. At a certain temperature, $K_p = 2.5 \times 10^4$ Pa. State what this tells you about the equilibrium partial pressure of CO_2, and explain why adding more $CaCO_3$(s) to the container has no effect on this value. **[2]**

d. The forward (decomposition) reaction is endothermic. State and explain the effect of decreasing the temperature on the value of K_p. **[2]**

Question 7 total: 8 marks

Question 8 — Extended response

Synoptic

A student says that increasing the total pressure of a gaseous equilibrium mixture always increases the value of K_p. Using your understanding of K_p, partial pressures and Le Chatelier's principle, evaluate this statement. Your answer should explain the difference between the effect of pressure on the position of equilibrium and its effect on K_p, and should explain what does change the value of K_p. **[6]**

This question is marked using a level of response.

Question 8 total: 6 marks

PAPER TOTAL: 76 MARKS

MARK SCHEME — Chapter 20: The Equilibrium Constant Kp

Award marks independently unless stated. ECF applies to calculations.

Q1 (a) [1]

- Mole fraction = (number of moles of that gas) ÷ (total number of moles of gas in the mixture). (1)

Q1 (b) [2]

- Partial pressure is the pressure that a gas in a mixture would exert if it alone occupied the container (at the same temperature). (1)
- Partial pressure = mole fraction × total pressure. (1)

Q1 (c) [5]

- Total moles = 2.00 + 6.00 + 4.00 = 12.00 mol. (1)
- Mole fractions: N_2 = 2.00/12.00 = 0.167; H_2 = 6.00/12.00 = 0.500; NH_3 = 4.00/12.00 = 0.333. (1)
- P(N_2) = 0.167 × 100 = 16.7 kPa. (1)
- P(H_2) = 0.500 × 100 = 50.0 kPa. (1)
- P(NH_3) = 0.333 × 100 = 33.3 kPa. (1)

Q1 (d) [2]

- Mole fraction of each = 0.500 (given equal, and only two gases present, so fractions must sum to 1). (1)
- P(X) = P(Y) = 0.500 × 300 = 150 kPa. (1)

Q2 (a) [12] — 3 marks each (expression + units)

- $K_p = (P_{NH3})^2 / (P_{N2}(P_{H2})^3)$; units = kPa^{-2}. (3)
- $K_p = (P_{SO3})^2 / ((P_{SO2})^2 P_{O2})$; units = kPa^{-1}. (3)
- $K_p = (P_{HI})^2 / (P_{H2}P_{I2})$; no units (dimensionless). (3)
- $K_p = (P_{NO2})^2 / ((P_{NO})^2 P_{O2})$; units = kPa^{-1}. (3)

Q3 (a) [3]

- Total moles = 0.60 + 1.40 = 2.00 mol. (1)
- Mole fraction N_2O_4 = 0.60 / 2.00 = 0.300. (1)
- Mole fraction NO_2 = 1.40 / 2.00 = 0.700. (1)

Q3 (b) [2]

- P(N_2O_4) = 0.300 × 200 = 60.0 kPa. (1)
- P(NO_2) = 0.700 × 200 = 140 kPa. (1)

Q3 (c) [4]

- $K_p = (P_{NO2})^2 / P_{N2O4}$. (1)
- $= (140)^2 \div 60.0 = 19600 \div 60.0$. (1)
- K_p = 327 kPa (3 s.f.). (1)
- Units: kPa. (1)

Q3 (d) [3]

- Rearranging: $P_{NO2} = \sqrt{(K_p \times P_{N2O4})}$. (1)
- $= \sqrt{(326.7 \times 80.0)} = \sqrt{26133}$. (1)
- P_{NO2} = 162 kPa (3 s.f.). (1)

ECF from the K_p value calculated in (c).

Q4 (a) [4]

- Initial: PCl_5 = 2.00, PCl_3 = 0, Cl_2 = 0. (1)
- Amount dissociated = 40.0% × 2.00 = 0.800 mol. (1)
- Change: PCl_5 = −0.800, PCl_3 = +0.800, Cl_2 = +0.800. (1)
- Equilibrium: PCl_5 = 1.20 mol, PCl_3 = 0.800 mol, Cl_2 = 0.800 mol. (1)

Q4 (b) [3]

- Total moles = 1.20 + 0.800 + 0.800 = 2.80 mol. (1)
- Mole fraction PCl_5 = 1.20/2.80 = 0.429; PCl_3 = 0.800/2.80 = 0.286. (1)
- Mole fraction Cl_2 = 0.800/2.80 = 0.286. (1)

Q4 (c) [3]

- P(PCl_5) = 0.429 × 150 = 64.3 kPa. (1)
- P(PCl_3) = 0.286 × 150 = 42.9 kPa. (1)
- P(Cl_2) = 0.286 × 150 = 42.9 kPa. (1)

Q4 (d) [3]

- $K_p = (P_{PCl3} \times P_{Cl2}) / P_{PCl5}$ = (42.9 × 42.9) ÷ 64.3. (1)
- = 1840 ÷ 64.3. (1)
- K_p = 28.6 kPa (3 s.f.). (1)

Q4 (e) [2]

- K_p would increase. (1)
- Increasing temperature favours the endothermic (forward) reaction, increasing the proportion of PCl_3 and Cl_2 relative to PCl_5 at equilibrium, so K_p increases. (1)

Q5 (a) [1]

- K_p is unaffected (stays constant). (1)

Q5 (b) [3]

- K_p is a constant that depends only on temperature. (1)
- Although the partial pressures of individual gases (and the position of equilibrium) change when total pressure changes, the amounts present adjust so that the K_p expression evaluates to the same numerical value. (1)
- K_p only changes if the temperature changes. (1)

Q5 (c) [3]

- The position of equilibrium shifts to the right, towards NH_3, since there are fewer moles of gas on the product side (2 mol vs 4 mol). (1)
- The yield/mole fraction of NH_3 at equilibrium increases. (1)
- The value of K_p does not change, because the temperature is constant. (1)

Q6 (a) [1]

- K_p decreases as temperature increases. (1)

Q6 (b) [3]

- Increasing temperature shifts the equilibrium in the endothermic direction, i.e. in reverse (towards reactants), for an exothermic forward reaction. (1)
- This decreases the equilibrium partial pressures of the products relative to the reactants. (1)
- Since K_p = (partial pressures of products)/(partial pressures of reactants) (raised to appropriate powers), a smaller products-to-reactants ratio means K_p decreases. (1)

Q6 (c) [2]

- K_p increases as temperature increases. (1)
- Increasing temperature favours the endothermic (forward) reaction, increasing the equilibrium partial pressures of products relative to reactants, so K_p increases. (1)

Q7 (a) [2]

- The "concentration" (activity) of a pure solid is constant regardless of the amount present, so it does not affect the position of equilibrium. (1)
- Its (constant) contribution is incorporated into the value of K_p itself, so it does not appear as a variable term in the expression. (1)

Q7 (b) [2]

- $K_p = P_{CO2}$ (2)

Q7 (c) [2]

- The equilibrium partial pressure of CO_2 must always equal 2.5×10^4 Pa at this temperature. (1)
- Adding more solid $CaCO_3$ does not appear in the K_p expression (it is a pure solid), so it does not shift the position of equilibrium or change P_{CO2}; only more solid is present at equilibrium. (1)

Q7 (d) [2]

- K_p would decrease. (1)
- Decreasing temperature favours the exothermic (reverse) reaction, reducing the equilibrium partial pressure of CO_2, and hence K_p. (1)

Q8 [6] — Level of response

- **Level 3 (5–6):** Clearly distinguishes the effect of pressure on position of equilibrium (can shift) from its effect on K_p (none), and correctly explains that only temperature changes K_p, with logical, well-structured reasoning.
- **Level 2 (3–4):** Correctly identifies that the student is wrong and gives a broadly correct explanation, but with the distinction between position of equilibrium and K_p, or the role of temperature, only partially explained.
- **Level 1 (1–2):** States that the student is incorrect with limited or generic reasoning; little reference to partial pressures, position of equilibrium, or the role of temperature.

Indicative content: *The student is incorrect. Changing the total pressure of a gaseous equilibrium can shift the position of equilibrium (towards the side with fewer gas moles, by Le Chatelier's principle), and this changes the individual partial pressures and amounts of each gas present — but it does not change the numerical value of K_p. This is because K_p is an equilibrium constant: at a fixed temperature, whatever adjustment occurs in the position of equilibrium happens precisely so that the ratio of partial pressures defined by the K_p expression remains the same. The only factor that changes the value of K_p is a change in temperature: increasing temperature increases K_p for an endothermic forward reaction (favouring products) and decreases K_p for an exothermic forward reaction (favouring reactants), because the equilibrium mixture's composition — and hence the ratio of partial pressures — genuinely changes at the new temperature. Pressure and concentration changes shift equilibrium position without changing K; only temperature changes K itself.*

END OF MARK SCHEME · 76 marks