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ANSWER BOOK

Kp: equilibria in the gas phase

Chemical equilibria · Unit C06

AQA 3.1.10 · OCR A 5.1.2

15 questions · 55 marks

NAVY EDITION

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SECTION B · Standard, 3 to 5 marks

B1 KE-Q8 [5]

M1 from 1 mol PCl_5: $(1 - \alpha)$ mol PCl_5, α mol PCl_3, α mol Cl_2, total $(1 + \alpha)$ mol. **M1** $p(PCl_5) = (1 - \alpha)P \div (1 + \alpha)$ and $p(PCl_3) = p(Cl_2) = \alpha P \div (1 + \alpha)$. **M1** $Kp = \alpha^2 P \div (1 - \alpha^2)$, so $150\alpha^2 \div (1 - \alpha^2) = 63.0$. **M1** $213\alpha^2 = 63.0$, so $\alpha^2 = 0.296$. **A1** $\alpha = 0.544$, with no units, so 54.4% of the PCl_5 dissociates.

B2 KE-Q7 [4]

M1 from 1.00 mol N_2O_4: 0.500 mol N_2O_4 and 1.00 mol NO_2 at equilibrium, total 1.50 mol. **M1** partial pressures: $p(N_2O_4) = (0.500 \div 1.50) \times 100 = 33.3$ kPa and $p(NO_2) = (1.00 \div 1.50) \times 100 = 66.7$ kPa. **M1** $Kp = p(NO_2)^2 \div p(N_2O_4) = 66.7^2 \div 33.3$. **A1** Kp = 133 kPa, to three significant figures.

B3 KE-Q11 [4]

B1 Kp for an endothermic forward reaction increases as the temperature rises. **B1** the ratio $p(NO_2)^2 \div p(N_2O_4)$ is now smaller than the new Kp, so the forward reaction runs faster until it matches, and more brown NO_2 forms. **B1** a catalyst increases the rates of the forward and reverse reactions equally, so the partial pressures at equilibrium and the colour are unchanged. **B1** Kp depends only on temperature, so the catalyst does not change it.

B4 KE-Q17 [4]

B1 at the instant of compression every partial pressure does double. **B1** the ratio $p(PCl_3) \times p(Cl_2) \div p(PCl_5)$ then doubles, because there are two pressure terms on top and one below, so it no longer equals Kp. **B1** the reverse reaction runs faster and the position shifts towards PCl_5 until the ratio falls back to Kp. **B1** Kp depends only on temperature, so the claim is wrong: the position changes and Kp does not.

B5 KE-Q18 [4]

M1 equal amounts of NH_3 and H_2S form, so $p(NH_3) = p(H_2S) = 0.660 \div 2 = 0.330$ atm. **M1** $Kp = p(NH_3) \times p(H_2S)$, the solid being left out, so $Kp = 0.330 \times 0.330 = 0.109$ atm^2. **M1** Kp has two powers of pressure, so the conversion factor is squared: $Kp = 0.1089 \times 101^2$. **A1** $Kp = 1.11 \times 10^3$ kPa^2, to three significant figures; error carried forward from M2.

B6 KE-Q19 [4]

B1 carbon is a solid, so it exerts no partial pressure and does not appear in the Kp expression. **B1** mole fractions are used to find partial pressures, so the total amount is the total amount of gas only, CO_2 and CO. **B1** there is one mole of gas on the left and two on the right; the solid carbon is not counted. **B1** raising the pressure shifts the position to the left, so the proportion of carbon monoxide falls while Kp is unchanged.

B7 KE-Q1 [3]

B1 mole fraction is the amount in moles of that gas divided by the total amount in moles of gas in the mixture. **B1** partial pressure is the pressure the gas would exert if it alone occupied the whole volume; accept mole fraction × total pressure. **B1** the partial pressures of all the gases add up to the total pressure.

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B8 KE-Q3

B1 $K_p = p(SO_3)^2 \div (p(SO_2)^2 \times p(O_2))$; reject an expression with square brackets. **B1** units in kPa: $kPa^2 \div kPa^3 = kPa^{-1}$. **B1** units in Pa: $Pa^2 \div Pa^3 = Pa^{-1}$. [3]

B9 KE-Q9

B1 Kp depends only on temperature, which is unchanged. **B1** raising the total pressure raises both partial pressures by the same factor, and because $p(NO_2)$ is squared the ratio $p(NO_2)^2 \div p(N_2O_4)$ becomes larger than Kp. **B1** the reverse reaction runs faster until the ratio equals Kp again, so the position shifts to the left, towards N_2O_4. [3]

B10 KE-Q13

B1 use the equation to find every equilibrium amount from the change in the measured one, in an ICE table. **B1** add the equilibrium amounts to give the total amount, and divide each amount by it to give the mole fractions. **B1** multiply each mole fraction by the total pressure to give the partial pressures, and substitute them into the Kp expression. [3]

B11 KE-Q14

B1 $K_p = p(CO_2)$, because solids do not appear in the expression. **B1** the units of Kp are kPa. **B1** at a given temperature the CO_2 settles at the pressure equal to Kp whatever the amount of solid present, as long as some of each solid remains. [3]

B12 KE-Q15

B1 each partial pressure is the mole fraction multiplied by the same total pressure P. **B1** the powers on top and bottom are both 2, so P^2 cancels and Kp equals the ratio of mole fractions, with no units. **B1** a change in P therefore leaves the ratio equal to Kp, so there is no shift in the position of equilibrium. [3]

B13 KE-Q16

B1 Kc is written with equilibrium concentrations in mol dm^{-3}, Kp with equilibrium partial pressures. **B1** both are built the same way from the balanced equation, with coefficients as powers, and their units come from the expression: powers of mol dm^{-3} for Kc, of kPa for Kp. **B1** both depend only on temperature and are unaffected by pressure, concentration or a catalyst. [3]

B14 KE-Q23

B1 $K_p = p(NO_2)^2 \div p(N_2O_4)$, so its units are $kPa^2 \div kPa = kPa$. **B1** $K_p = p(HI)^2 \div (p(H_2) \times p(I_2))$ has two pressures above the line and two below, so $kPa^2 \div kPa^2$ cancels and Kp is a pure number. **B1** the unit depends on the difference between the numbers of moles of gas on the two sides: the first equation has one more mole of gas on the right, the second has equal numbers. [3]

SECTION C · Long, 6 marks or more

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C1 KE-Q22 **Indicative content** [6]

B1 each partial pressure is the mole fraction multiplied by the total pressure P, so Kp = $x(NH_3)^2P^2 \div (x(N_2)P \times x(H_2)^3P^3)$. **B1** this simplifies to Kp = $(x(NH_3)^2 \div (x(N_2)x(H_2)^3)) \times P^{-2}$, because there are two moles of gas on the right and four on the left. **B1** at constant temperature Kp is constant, so when P rises the ratio of mole fractions must rise by the factor P^2 to keep Kp the same. **B1** that ratio can rise only if nitrogen and hydrogen react to form ammonia, so the position shifts right and the mole fraction of ammonia increases. **B1** raising the temperature, by contrast, decreases the value of Kp itself, because the forward reaction is exothermic. **B1** the ratio of partial pressures is then larger than the new Kp, so the reverse reaction runs faster and the position shifts left, lowering the proportion of ammonia.

Levels

Level 3 (5–6 marks) Kp is written in mole fractions and simplified to show the P^{-2} factor, the constancy of Kp at fixed temperature is used to show that the ratio of mole fractions must rise with P and so ammonia must form, and the temperature effect is explained through the change in Kp itself; every step follows from the one before and the algebra is correct.

Level 2 (3–4 marks) Kp is written correctly in mole fractions and the pressure effect is argued from Kp staying constant; the P^{-2} simplification, or the smaller Kp at higher temperature, is not shown.

Level 1 (1–2 marks) Kp is written, or higher pressure is said to favour ammonia because there are fewer moles of gas; Kp itself is usually said to increase with pressure.

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