Equilibrium

Standard difficulty · 20 questions · 40 marks · Time: 36 minutes

Name: _____ Date: _____ Score: ____ / 40

Show your working for Sections B and C. Answers are on the last page — try every question first!

Section A — Choose the correct answer 8 × 1 = 8 marks

1. At equilibrium, the rates of the forward and backward reactions are:

(a) forward faster than backward **(b)** backward faster than forward

(c) both zero **(d)** equal

2. For $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, the equilibrium concentrations are $[SO_2] = 0.5$ M, $[O_2] = 0.5$ M, $[SO_3] = 0.5$ M. K_c is:

(a) 2 **(b)** 0.5 **(c)** 4 **(d)** 1

3. For $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$, K_p and K_c are related by:

(a) $K_p = K_c(RT)^{-2}$ **(b)** $K_p = K_c(RT)$

(c) $K_p = K_c$ **(d)** $K_p = K_c(RT)^2$

4. For $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, $\Delta H = -92.4$ kJ/mol, if a catalyst is added, the equilibrium:

(a) does not shift **(b)** shifts to the right (forward)

(c) shifts to the left (backward) **(d)** stops completely

5. The pH of a 1×10^{-4} M solution of nitric acid (HNO_3) at 298 K is: (assume complete ionisation)

(a) 4 **(b)** 3 **(c)** 10 **(d)** 5

6. The solubility of Ag_2SO_4 in water is 7×10^{-2} mol/L. Its solubility product is:

(a) 1.372×10^{-4} **(b)** 4.9×10^{-3} **(c)** 1.372×10^{-2} **(d)** 1.372×10^{-3}

7. The conjugate acid of OH^- is:

(a) H_2CO_3 **(b)** SO_4^{2-} **(c)** H_2O **(d)** $H_2PO_4^-$

8. Assertion (A): Increasing the pressure on $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ shifts the equilibrium to the left.
Reason (R): Increasing the pressure shifts an equilibrium towards the side with fewer moles of gas.

(a) Both A and R are true, and R is the correct explanation of A.

(b) Both A and R are true, but R is not the correct explanation of A.

(c) A is true, but R is false.

(d) A is false, but R is true.

Section B — Short answer 8 × 2 = 16 marks

9. State Le Chatelier's principle.

10. 0.5 mol of N_2O_4 is heated in a 2 L vessel. At equilibrium 60% of it has dissociated ($N_2O_4(g) \rightleftharpoons 2NO_2(g)$). Find K_c. (2 decimal places where needed.)

11. The ionisation constant of a weak base BOH is 1×10^{-5}. Find $[OH^-]$, the pH and the degree of ionisation of a 0.001 M solution at 298 K.

12. A solution has $[OH^-] = 4 \times 10^{-6}$ M at 298 K. Find its pH and pOH. (log 4 = 0.6021)

13. At equilibrium, the partial pressures for $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ are CH_4 2 bar, H_2O 2 bar, CO 4 bar, H_2 1 bar. Find K_p. (2 decimal places where needed.)

14. The solubility product of CaF_2 is 2.048×10^{-9}. Find its solubility in mol/L.

15. A buffer contains 0.1 M ethanoic acid (CH_3COOH) and 0.05 M of its sodium salt. Find its pH. (pKa = 4.76) (log 2 = 0.3010, log 5 = 0.6990)

16. For $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$, K_c = 10. At one moment $[PCl_5] = 2$ M, $[PCl_3] = 0.1$ M, $[Cl_2] = 1$ M. Find Q and say which way the reaction goes. (2 decimal places where needed.)

Section C — Word problems — 4 × 4 = 16 marks

17. Explain the effect of changing concentration, pressure, temperature and adding a catalyst on the equilibrium $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, $\Delta H = -92.4$ kJ/mol.

18. 4 mol each of H_2 and I_2 are heated in a 2 L vessel: $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$, $K_c = 4$. Find the equilibrium concentrations of H_2, I_2 and HI. (2 decimal places where needed.)

19. A weak acid HA has $K_a = 1 \times 10^{-3}$. For a 0.1 M solution at 298 K find (a) $[H^+]$, (b) the pH, (c) the degree of ionisation. (d) What is the pH after the solution is diluted 10 times?

20. The solubility product of PbI_2 is 2.048×10^{-6}. (a) Find its solubility in pure water. (b) Find its solubility in a solution in which $[I^-] = 0.05$ M (from a soluble salt). (c) Explain the difference.

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Answer key

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Q	Answer	Working
1	**(d) equal**	equilibrium is dynamic
2	**(a) 2**	$K_c = [SO_3]^2 / ([SO_2]^2[O_2])$
3	**(d) $K_p = K_c(RT)^2$**	$K_p = K_c(RT)^{\Delta n}$ with $\Delta n = 2$
4	**(a) does not shift**	Le Chatelier: it shifts a catalyst speeds up both directions equally
5	**(a) 4**	$[H^+] = 1 \times 1 \times 10^{-4} = 10^{-4}$ M
6	**(d) 1.372×10^{-3}**	$Ag_2SO_4 \rightleftharpoons 2Ag^+ + SO_4^{2-}$, so $K_{sp} = 4s^3$
7	**(c) H_2O**	add one H^+
8	**(d) A is false, but R is true.**	A is false: $\Delta n = -1$. R is true.
9	**If a system at equilibrium is disturbed by a change in concentration, pressure or temperature, it shifts in the direction that tends to undo the change.**	—
10	**$K_c = 0.9$ ($[N_2O_4] = 0.1$ M, $[NO_2] = 0.3$ M)**	initial 0.25 M; use an ICE table with α
11	**$[OH^-] = 1 \times 10^{-4}$ M; pH = 10; α = 10%**	$[OH^-] = \sqrt{(K_b \times c)}$; $pOH = -\log[OH^-]$; $pH = 14 - pOH$
12	**pOH = 5.3979; pH = 8.6021**	$pOH = -\log(4 \times 10^{-6}) = 6 - \log 4$; $pH + pOH = 14$
13	**$K_p = 1$**	$K_p = p(CO) \times p(H_2)^3 / (p(CH_4) \times p(H_2O))$
14	**8×10^{-4} mol/L**	$K_{sp} = 4s^3$, so $s = \sqrt[3]{(K_{sp}/4)}$
15	**pH = 4.459**	$pH = pK_a + \log([salt]/[acid]) = 4.76 + \log 0.5$
16	**Q = 0.05; it goes forward (Q < K)**	$Q = [PCl_3][Cl_2] / [PCl_5]$ with these concentrations
17	**Adding N_2 or H_2, or removing NH_3, shifts it to the right. Raising the pressure shifts it to the right (4 mol of gas become 2). Raising the temperature shifts it to the left (the forward reaction is exothermic) and lowers K. A catalyst (iron) only makes equilibrium come faster. So high pressure, moderate temperature (about 700 K) and a catalyst are used in the Haber process.**	—
18	**$[H_2] = [I_2] = 1$ M; $[HI] = 2$ M**	if x mol reacts: $(2x)^2/(4 - x)^2 = 4$, so $2x/(4 - x) = 2$, $x = 2$
19	**(a) 1×10^{-2} M; (b) 2; (c) 10%; (d) 2.5**	$[H^+] = \sqrt{(K \times c)}$; after dilution c is 10 times smaller
20	**(a) 8×10^{-3} mol/L; (b) 8.19×10^{-4} mol/L; (c) the common ion shifts $PbI_2(s) \rightleftharpoons Pb^{2+} + 2I^-$ to the left (common ion effect), so less dissolves**	(a) $K_{sp} = 4s^3$; (b) $K_{sp} = s \times (0.05)^2$