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Topic 7.5: Magnitude of the Equilibrium Constant

Worksheet · AP Chemistry

UNIT 7 · EQUILIBRIUM

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How to Use This Worksheet

Work in order. Section A checks the building blocks: the three size regimes of K, what K does not say about rate, and what can change K. Section B prices the regimes out with equilibrium rows, particle snapshots, a temperature pair, a catalyst case, and K = 1 with powers. Section C is exam style: an ammonia mixture checked against its K, a ranking with a near 1 solve, and five claims to judge.

Reference facts. K >> 1 means products dominate at equilibrium; K << 1 means reactants dominate; K near 1 means appreciable amounts of both sides. K is a pure number without units, quoted at a stated temperature, and only temperature changes it. K says nothing about rate, and a catalyst does not change K. Percent conversion means the amount of a reactant converted divided by the amount it started with, times 100. In particle snapshots, counts are proportional to concentrations because every snapshot uses the same volume.

Do not look at the answer key until you have attempted every question.

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Section A: Recall and Concepts

A1. (a) State what the size of K describes. (b) Describe the equilibrium mixture when K >> 1, when K << 1, and when K is close to 1. (c) State whether K says anything about how quickly equilibrium is reached, and name what does govern that.

A2. For A(g) ⇌ B(g), $K = 4.0 \times 10^{3}$. A flask starts with [A] = 0.50 mol L^{-1} and no B. (a) State which side dominates the equilibrium mixture. (b) Write [B] = x and [A] = 0.50 − x, substitute into the K expression, and solve for x. (c) State the equilibrium value of [A] and the percent of A converted.

A3. Rank these K values from least to greatest extent of reaction at equilibrium: 2.5×10^{-6}, 0.85, 7.4×10^{5}, 1.0. Then state which two give mixtures with appreciable amounts of both sides, and why.

A4. A flask holds A(g) ⇌ B(g) in a fixed volume. It starts with 16 A particles and no B. The equilibrium snapshot shows 13 A particles and 3 B particles. (a) Calculate K from the snapshot. (b) State which side is favoured at equilibrium. (c) Calculate the percent of A converted.

A5. Judge each statement, giving the reason. (a) "$K = 10^{6}$, so the reaction reaches equilibrium in milliseconds." (b) "A catalyst raises K, because it makes products form faster." (c) "K << 1, so the forward reaction does not occur." (d) "Raising the temperature always increases K."

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Section B: Core Practice

B1. Two reactions from Topic 7.4. Reaction (i): $CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$, $K_c = 1.0 \times 10^2$; a flask starting with $[CO] = [Cl_2] = 0.20$ mol L^{-1} settles with $[CO] = [Cl_2] = 0.040$ and $[COCl_2] = 0.16$ mol L^{-1}. Reaction (ii): $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, $K_c = 0.040$; a flask starting with $[N_2O_4] = 0.200$ mol L^{-1} settles with $[N_2O_4] = 0.160$ and $[NO_2] = 0.080$ mol L^{-1}. (a) Verify each K_c by substitution. (b) Calculate the percent conversion of CO in (i) and of N_2O_4 in (ii). (c) State which reaction lies further toward products, and how the two percentages support that. (d) A third reaction, $A(g) \rightleftharpoons B(g)$, has $K = 1.0 \times 10^{-7}$. Predict the equilibrium [B] and the percent conversion for a flask starting with 1.0 mol L^{-1} of A, explaining the approximation you use.

B2. Two different $A(g) \rightleftharpoons B(g)$ reactions are held in identical volumes, and each flask starts with 12 A particles and no B. At equilibrium, box 1 shows 3 A particles and 9 B particles; box 2 shows 10 A particles and 2 B particles. (a) Calculate K for each reaction. (b) Rank the two reactions by extent of reaction. (c) Calculate the percent of A converted in each box. (d) Both flasks started identically, yet settled differently. Explain why, briefly.

B3. A reaction has $K = 6.3 \times 10^{-2}$ at 500 K and $K = 4.1 \times 10^2$ at 800 K. (a) Describe the equilibrium mixture at each temperature. (b) State what raising the temperature does to the equilibrium position for this reaction. (c) A student concludes: "The reaction must be faster at 800 K, because K is larger there." Identify exactly what is wrong with the reasoning, and state what K comparison alone entitles the student to claim.

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B4. A reaction has K = 3.2×10^{15} at 298 K. (a) Describe the equilibrium mixture obtained by starting from pure reactants, including what can be said about the reactant that remains. (b) A catalyst is added to the equilibrium mixture. State the effect on K, on the equilibrium position, and on the time the mixture takes to reach equilibrium if it is disturbed. (c) The reaction $2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(g)$ also has an enormous K at room temperature, yet a hydrogen and oxygen mixture can sit for years without reacting. Explain how both facts hold at once.

B5. For $A(g) \rightleftharpoons 2B(g)$, K = 1.0 at the temperature used. (a) Show that the mixture [A] = 0.25 and [B] = 0.50 mol L^{-1} satisfies K = 1.0. (b) A student claims K = 1.0 requires [A] = [B]. Use part (a) to refute the claim, stating which species is actually present in greater amount. (c) Show that the mixture [A] = 1.0 and [B] = 1.0 mol L^{-1} also satisfies K = 1.0, and state what the pair of mixtures demonstrates about what a near 1 K fixes and what it leaves free.

B6. Three $A(g) \rightleftharpoons B(g)$ reactions at the same temperature each start with 1.0 mol L^{-1} of A and no B: reaction P has K = 4.0×10^{4}, reaction Q has K = 1.5, and reaction R has K = 2.0×10^{-3}. (a) For each reaction, solve for the equilibrium [B] and the percent of A converted. (b) Rank the reactions by extent of reaction. (c) State which reaction has appreciable amounts of both A and B at equilibrium, and point to the numbers that show it.

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Section C: Exam Style

C1. For $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ at 500 K, Kc = 0.040. A flask starts with $[N_2] = 0.30$ and $[H_2] = 1.15$ mol L^{-1} and no NH_3, and settles with $[N_2] = 0.25$, $[H_2] = 1.0$ and $[NH_3] = 0.10$ mol L^{-1}. (a) From the size of Kc alone, state which side is favoured at equilibrium. (b) Verify Kc by substituting the equilibrium row. (c) Show that the equilibrium row is consistent with the starting mixture, checking the changes against the coefficients, and calculate the percent conversion of N_2. (d) A student concludes from Kc = 0.040 that no ammonia forms. Correct the claim using your answer to (c).

C2. Three reactions at the same temperature: (i) $K = 7.0 \times 10^{-12}$, (ii) K = 0.95, (iii) $K = 6.0 \times 10^{7}$. (a) Rank them from least to greatest extent of reaction. (b) Reaction (ii) is $A(g) \rightleftharpoons B(g)$. A flask starts with $[A] = 2.0$ mol L^{-1} and no B. Solve for the equilibrium row and the percent of A converted. (c) Describe the equilibrium mixture of reaction (i) as a particle snapshot, starting from pure A. (d) A student says reaction (iii) must be instantaneous. Respond, naming the quantity that would actually decide the speed.

C3. Judge each claim, supporting each verdict with the idea it depends on. (a) "For $2A(g) \rightleftharpoons B(g)$ with $K = 10^{3}$, [B] is 1000 times [A] at equilibrium." (b) "If $K << 1$, the reverse reaction does not occur." (c) "Reactions with K = 0.80 and K = 1.25 must have very different equilibrium mixtures." (d) "Adding a catalyst will make a reaction with $K = 10^{-4}$ favour products." (e) "The hydrogen and oxygen mixture that sits unreacted for years proves that its K is small."

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Answer Key

A1. (a) The size of K describes the equilibrium mixture: how it is divided between products and reactants, powers included. (b) K >> 1: almost entirely products, with only a trace of reactant remaining; the reaction goes essentially to completion. K << 1: almost entirely reactants, with very little product formed. K close to 1: appreciable amounts of both sides, neither dominating. (c) Nothing. K is thermodynamic and fixes only the position; the time taken to reach equilibrium is kinetic, governed by activation energy.

A2. (a) Products: $K = 4.0 \times 10^3 >> 1$, so B dominates and A is nearly used up. (b) $K = x / (0.50 - x) = 4.0 \times 10^3$, so $x = 4.0 \times 10^3 (0.50 - x) = 2000 - 4.0 \times 10^3 x$, giving $(1 + 4.0 \times 10^3) x = 2000$ and $x = 2000 / 4001 = 0.4999$ mol L^{-1}. (c) $[A] = 0.50 - 0.4999 = 0.0001$ mol L^{-1} (1.2×10^{-4} to two significant figures); the percent converted is $0.4999 / 0.50 \times 100 = 99.98\%$. Essentially complete, as the large K required, though a trace of A remains.

A3. Least to greatest: 2.5×10^{-6}, then 0.85, then 1.0, then 7.4×10^5. Extent follows the size of K directly. The two with appreciable amounts of both sides are 0.85 and 1.0: both are close to 1, so neither side is squeezed to a trace.

A4. (a) Counts are proportional to concentrations in the same volume, so $K = [B] / [A] = 3 / 13 = 0.23$. (b) Reactants are favoured: $K < 1$, and the snapshot itself shows far more A than B. (c) A converted = 16 − 13 = 3 particles of the 16 that started, so the percent converted is $3 / 16 \times 100 = 18.75\%$, about 19%.

A5. (a) False. K carries no time information. A reaction with $K = 10^6$ has an equilibrium far toward products, but reaches it at a rate set by its activation energy, which could make it fast or extremely slow. (b) False. A catalyst speeds the forward and reverse reactions equally, so the equilibrium position, and with it K, is unchanged; it only shortens the time taken to get there. (c) False. The forward reaction does occur; it simply produces very little product before the reverse rate rises to match it. The product amount at equilibrium is tiny, not zero. (d) False. Temperature is the only thing that changes K, but it can lower K as well as raise it, depending on the reaction, so "always increases" is wrong.

B1. (a) Reaction (i): $K_c = [COCl_2] / ([CO][Cl_2]) = 0.16 / (0.040 \times 0.040) = 0.16 / 0.0016 = 1.0 \times 10^2$, as stated. Reaction (ii): $K_c = [NO_2]^2 / [N_2O_4] = (0.080)^2 / 0.160 = 0.0064 / 0.160 = 0.040$, as stated. (b) In (i), CO falls from 0.20 to 0.040, so the percent converted is $0.16 / 0.20 \times 100 = 80\%$. In (ii), N_2O_4 falls from 0.200 to 0.160, so the percent converted is $0.040 / 0.200 \times 100 = 20\%$. (c) Reaction (i) lies much further toward products: its Kc is far above 1 while (ii) is below 1, and the conversions agree, 80% against 20%. (d) With [B] = x and [A] = 1.0 − x, $K = x / (1.0 - x) = 1.0 \times 10^{-7}$. Because K is so small, x is tiny and $1.0 - x \approx 1.0$, so $x \approx 1.0 \times 10^{-7}$ mol L^{-1}. The percent converted is about $1.0 \times 10^{-7} / 1.0 \times 100 = 1.0 \times 10^{-5}$ %. (Exact solution: $x = 9.99999 \times 10^{-8}$.)

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B2. (a) Box 1: K = 9 / 3 = 3.0. Box 2: K = 2 / 10 = 0.20. Counts stand in for concentrations because the volumes are identical. (b) Box 1's reaction has the greater extent: the larger K lies further toward products. (c) Box 1: 9 of 12 converted, 9 / 12 × 100 = 75%. Box 2: 2 of 12 converted, 2 / 12 × 100 = 16.7%, about 17%. (d) The flasks belong to different reactions, and each settles where its own K dictates.

B3. (a) At 500 K, $K = 6.3 \times 10^{-2} << 1$, so the mixture is mostly reactants with little product. At 800 K, $K = 4.1 \times 10^{2} >> 1$, so the mixture is mostly products. (b) Heating moves the equilibrium position toward products, carrying it across K = 1 from reactant favoured to product favoured. (c) The reasoning treats K as evidence about rate, and K contains no rate information: it is a ratio of equilibrium concentrations. The comparison entitles the student to claim only that the equilibrium position at 800 K lies much further toward products than at 500 K. Speed would need kinetic evidence, not a larger K.

B4. (a) The mixture is essentially all products: $K = 3.2 \times 10^{15}$ means the product terms outweigh the reactant terms by a factor of order 10^{15}. The reactant remaining is a trace, far below anything measurable. (b) K: unchanged. Position: unchanged, because the catalyst lowers the activation energy of both directions equally. Time: shorter, since with both rates larger the disturbed mixture returns to the same equilibrium sooner. (c) Both facts hold because position and speed are independent. The enormous K fixes the position: overwhelmingly toward water. The stillness is kinetic: the activation energy is high, so almost no collisions succeed at room temperature, and the mixture waits for a spark.

B5. (a) $K = [B]^2 / [A] = (0.50)^2 / 0.25 = 0.25 / 0.25 = 1.0$, as required. (b) Refuted by the numbers: here [B] = 0.50 is twice [A] = 0.25, yet K is exactly 1.0. The square on [B] lets a larger B concentration satisfy the same K, so K = 1 constrains the expression, not the individual concentrations. (c) $K = (1.0)^2 / 1.0 = 1.0$, also satisfied. Together the mixtures show that a K of 1 fixes only the value of the full expression; many mixtures satisfy it, and all hold appreciable amounts of both sides.

B6. (a) For A ⇌ B starting at 1.0 mol L^{-1}, $K = x / (1.0 - x)$ with x = [B] at equilibrium, so $x = K / (1 + K)$. Reaction P: $x = 4.0 \times 10^{4} / (1 + 4.0 \times 10^{4}) = 0.99998$, so [B] ≈ 1.0 mol L^{-1} and the percent converted is 99.998%, effectively complete. Reaction Q: x = 1.5 / 2.5 = 0.60 mol L^{-1}, 60% converted. Reaction R: $x = 2.0 \times 10^{-3} / (1 + 2.0 \times 10^{-3}) = 0.0020$ mol L^{-1}, 0.20% converted. (b) Greatest to least: P, then Q, then R, following the K values. (c) Reaction Q: its row, [A] = 0.40 and [B] = 0.60 mol L^{-1}, holds substantial amounts of both, exactly what K near 1 means. P leaves only about 2.5×10^{-5} mol L^{-1} of A, and R makes only 0.0020 mol L^{-1} of B.

C1. (a) Reactants are favoured: Kc = 0.040 << 1, so most of the nitrogen and hydrogen remain unreacted and only a modest amount of ammonia forms. (b) $Kc = [NH_3]^2 / ([N_2][H_2]^3) = (0.10)^2 / (0.25 \times (1.0)^3) = 0.010 / 0.25 = 0.040$, matching the given constant. (c) N_2 falls by 0.30 − 0.25 = 0.05. The coefficients then require H_2 to fall by 3 × 0.05 = 0.15, from 1.15 to 1.0, as observed, and NH_3 to rise by 2 × 0.05 = 0.10, as observed. The row is consistent. Percent conversion of N_2 = 0.05 / 0.30 × 100 =

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16.7%, about 17%. (d) Kc < 1 means reactants dominate, not that products are absent. Here one sixth of the nitrogen is converted, giving $[NH_3]$ = 0.10 mol L^{-1} at equilibrium: a small yield, but very far from none.

C2. (a) Least to greatest: (i) 7.0×10^{-12}, then (ii) 0.95, then (iii) 6.0×10^{7}. Extent follows the size of K. (b) K = x / (2.0 − x) = 0.95, so x = 0.95(2.0 − x) = 1.9 − 0.95x, giving 1.95x = 1.9 and x = 0.97 mol L^{-1}. The equilibrium row is [A] = 2.0 − 0.97 = 1.03 and [B] = 0.97 mol L^{-1}, and the percent converted is 0.97 / 2.0 × 100 = 49%. Check, with unrounded values: 0.974 / 1.026 = 0.95, as required; the near equal row is what K near 1 looks like. (c) Almost entirely A particles: with $K = 7.0 \times 10^{-12}$ the product side is squeezed to a vanishing trace, so a snapshot shows reactant particles with, for practical purposes, no B among them. (d) $K = 6.0 \times 10^{7}$ says the equilibrium lies far toward products; it says nothing about time. Speed is decided by kinetics, above all the activation energy.

C3. (a) False. K is the full expression, $[B] / [A]^2$ here, not the ratio [B] / [A]. With [A] = 0.10 and [B] = 10 mol L^{-1}, $K = 10 / (0.10)^2 = 1.0 \times 10^{3}$ while [B] is only 100 times [A]. (b) False. Equilibrium is dynamic: the reverse reaction runs at the same rate as the forward reaction. A small K means the mixture is mostly reactants, not that either direction has stopped. (c) False. Both values are near 1, so both mixtures hold appreciable amounts of both sides; neither is dominated by one side, and the mixtures are far more alike than the claim suggests. (d) False. A catalyst speeds both directions equally and leaves K and the position unchanged. A reaction with $K = 10^{-4}$ stays reactant favoured; the catalyst only gets it there faster. (e) False. The stillness is kinetic: a high activation energy with no spark to overcome it. The reaction's K is in fact enormous, with equilibrium overwhelmingly toward water.

Continue Revising

Topic 7.5 Revision Notes

Topic 7.5 Quiz: Magnitude of the Equilibrium Constant

Previous Worksheet: Topic 7.4 Calculating the Equilibrium Constant

Next Worksheet: Topic 7.6 Properties of the Equilibrium Constant

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