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Topic 7.6: Properties 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 three manipulation rules on their own: reversing, scaling, and adding. Section B combines them the way exam questions do, including preparing a step before adding it and checking a manipulated constant against a real equilibrium mixture. Section C is exam style: a carbon monoxide target built from two steps, an HI constant manipulated three ways, and five claims to judge.

Reference facts. Reversing a reaction inverts K: K reverse = 1 / K forward. Multiplying every coefficient by n raises K to the power n: K new = (K old)^n, so halving takes the square root. Adding reactions multiplies their constants: K overall = $K_1 \times K_2$, with intermediates cancelling. K is never negative, and only temperature changes K for a fixed written equation.

Conventions: every K is quoted for its equation exactly as written, at one stated temperature. Fractional coefficients are allowed, and a halved equation is written per mole of its first species. When a mixture is given, substituting it into an expression must return the constant belonging to that written form.

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

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Section A: Recall and Concepts

A1. State the rule for finding the new equilibrium constant when a reaction is (a) written in reverse, (b) multiplied by a number n throughout, (c) obtained by adding two reactions together. In each case, name what happens to the K expression itself that causes the rule.

A2. For A(g) ⇌ B(g), K = 5.0 at the temperature used. Calculate K for (a) B(g) ⇌ A(g), (b) 2A(g) ⇌ 2B(g), (c) 3A(g) ⇌ 3B(g).

A3. For 2A(g) ⇌ B(g), K = 81. (a) Write the equation with all coefficients halved. (b) Calculate K for the halved equation. (c) State the operation you applied to the constant, and why halving the constant itself would be wrong.

A4. Step 1: A(g) ⇌ B(g), K_1 = 0.50. Step 2: B(g) ⇌ C(g), K_2 = 4.0. (a) Write the overall reaction obtained by adding the steps, naming the intermediate. (b) Calculate K for the overall reaction. (c) A student adds the constants and gets 4.5. Use the two K expressions to show why the product, not the sum, is correct.

A5. Judge each statement, giving the reason. (a) "Doubling every coefficient doubles K." (b) "The reverse reaction has a negative K, because the reaction runs the other way." (c) "Adding a catalyst produces a new K, because equilibrium is reached faster." (d) "Compressing the mixture increases K, because the concentrations all rise." (e) "K = 5.0 for A(g) ⇌ B(g) and K = 25 for 2A(g) ⇌ 2B(g) contradict each other."

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Section B: Core Practice

B1. For $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, $K = 6.0 \times 10^5$ at the temperature used. Calculate K for (a) $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$, (b) $\frac{1}{2}N_2(g) + 3/2H_2(g) \rightleftharpoons NH_3(g)$, (c) $2N_2(g) + 6H_2(g) \rightleftharpoons 4NH_3(g)$. For each part, name the manipulation you applied.

B2. For $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, an equilibrium mixture has $[SO_2] = 0.20$, $[O_2] = 0.10$ and $[SO_3] = 1.0$ mol L^{-1}. (a) Verify that $K = 2.5 \times 10^2$ for the equation as written. (b) Write the halved equation and calculate its K by substituting the same mixture into the halved expression. (c) Confirm that your answer to (b) is the square root of your answer to (a), and state in one sentence why the same mixture returns two different constants.

B3. Step 1: $2A(g) \rightleftharpoons B(g) + C(g)$, $K_1 = 4.0$. Step 2: $B(g) \rightleftharpoons 2D(g)$, $K_2 = 0.50$. (a) Add the steps and write the overall reaction, naming the intermediate. (b) Calculate K for the overall reaction. (c) Show the cancellation in the multiplied K expressions that mirrors the cancellation of the intermediate in the equations.

B4. Step 1: $A(g) \rightleftharpoons B(g)$, $K_1 = 5.0$. Step 2: $C(g) \rightleftharpoons B(g)$, $K_2 = 0.10$. The target reaction is $A(g) \rightleftharpoons C(g)$. (a) Explain why step 2 cannot be added as written. (b) Prepare step 2, stating its new constant. (c) Add the steps and calculate K for the target reaction. (d) Verify the result with the mixture $[A] = 0.10$, $[B] = 0.50$ and $[C] = 5.0$ mol L^{-1} by checking all three constants against it.

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B5. For A(g) + B(g) ⇌ C(g), K = 12 at the temperature used. Calculate K for (a) C(g) ⇌ A(g) + B(g), (b) 2C(g) ⇌ 2A(g) + 2B(g). (c) For part (b), state the two manipulations in the order you applied them and the constant after each one. (d) A classmate works a Q comparison for the equation in part (b) but compares the Q value against K = 12. State the error in one sentence.

B6. For ½N_2(g) + ½O_2(g) ⇌ NO(g), K = 2.1 × 10^{-16}. (a) Calculate K for N_2(g) + O_2(g) ⇌ 2NO(g). (b) Calculate K for the reverse of the doubled reaction, 2NO(g) ⇌ N_2(g) + O_2(g). (c) State what the size of your answer to (a) says about the equilibrium mixture of nitrogen and oxygen, and why doubling the equation did not change that conclusion.

Section C: Exam Style

C1. At one temperature, step 1: C(s) + O_2(g) ⇌ CO_2(g), K_1 = 2.0 × 10^2, and step 2: 2CO(g) + O_2(g) ⇌ 2CO_2(g), K_2 = 4.0 × 10^2. The target reaction is 2C(s) + O_2(g) ⇌ 2CO(g). (a) State how each step must be used: how many times, and in which direction. (b) Add the prepared steps and show that CO_2 cancels, leaving the target reaction. (c) Calculate K for the target reaction. (d) Explain why C(s) appears in none of the K expressions, and why that does not affect the manipulation rules.

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C2. For $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ at one temperature, Kc = 54, and an equilibrium mixture has $[H_2] = [I_2] = 0.214$ and $[HI] = 1.57$ mol L^{-1}. (a) Verify Kc by substitution. (b) Calculate K for $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$, and verify it against the same mixture. (c) Calculate K for $\frac{1}{2}H_2(g) + \frac{1}{2}I_2(g) \rightleftharpoons HI(g)$, and verify it against the same mixture. (d) Calculate K for $4HI(g) \rightleftharpoons 2H_2(g) + 2I_2(g)$ in two ways: from the original constant, and from your answer to (b). State what the agreement demonstrates. (e) Two of the four constants in this question are below 1. Identify them, and state what a below 1 constant means for the equilibrium mixture of its own written equation.

C3. Judge each claim, supporting each verdict with the rule it depends on. (a) "I multiplied the equation by 3, so the new K is three times the old one." (b) "The forward K is 0.25, so the reverse K is 4.0 and the reverse reaction favours its products." (c) "Two steps with $K_1 = 2.0$ and $K_2 = 5.0$ give an overall K of 7.0." (d) "Halving $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, whose K is 2.5×10^2, gives a halved equation with $K = 1.25 \times 10^2$." (e) "Once I know K for an equation, I can halve the equation but keep using the same K in my Q comparison."

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Answer Key

A1. (a) Reverse: the new constant is the reciprocal, 1 / K. Reversing swaps the numerator and denominator of the expression, so the value inverts. (b) Multiply by n: the new constant is K^n. Every concentration is raised to n times its former power, so the whole expression is raised to the power n. (c) Add: the new constant is the product $K_1 \times K_2$. The expressions multiply, and the intermediate appears once in a numerator and once in a denominator, so it cancels. Halving, used in later questions, is the multiply rule with n equal to one half: the new constant is the square root of the old one.

A2. (a) Reverse: 1 / 5.0 = 0.20. (b) Doubled: $5.0^2 = 25$. (c) Tripled: $5.0^3 = 125$. Each multiplier applied to the equation becomes the power applied to the constant.

A3. (a) A(g) ⇌ ½B(g). (b) Halving raises K to the one half power: √81 = 9.0. (c) The operation is the square root. Halving the constant itself would give 40.5, which belongs to no written form of this reaction: the coefficients were halved, not the ratio of concentrations, and the expression's powers are what changed.

A4. (a) A(g) ⇌ C(g); the intermediate is B, which is produced in step 1 and consumed in step 2. (b) $K = K_1 \times K_2 = 0.50 \times 4.0 = 2.0$. (c) The step expressions are [B] / [A] and [C] / [B]. Multiplied together they give ([B] / [A]) × ([C] / [B]) = [C] / [A], exactly the expression of the overall reaction, with [B] cancelling. Addition of the constants, 4.5, corresponds to no combination of the expressions at all.

A5. (a) False. Doubling raises K to the second power. (b) False. K is a ratio of concentrations, so it is always positive; reversing gives the reciprocal, not a negative. (c) False. A catalyst shortens the time taken to reach equilibrium and changes neither the settled mixture nor K. (d) False. Compression changes the concentrations, and the mixture then readjusts so that the same K is satisfied; only temperature produces a new K. (e) False. The two constants belong to two written forms of the same reaction, and $25 = 5.0^2$ is exactly what the doubling rule requires. They describe one mixture, not two conflicting ones.

B1. (a) Reverse: $1 / (6.0 \times 10^5) = 1.7 \times 10^{-6}$. (b) Halve: $\sqrt{(6.0 \times 10^5)} = 7.7 \times 10^2$. The halved equation is written per mole of NH_3. (c) Double: $(6.0 \times 10^5)^2 = 3.6 \times 10^{11}$. In each case the manipulation applied to the equation is applied to the constant as the matching power or reciprocal.

B2. (a) $K = [SO_3]^2 / ([SO_2]^2[O_2]) = (1.0)^2 / ((0.20)^2 \times 0.10) = 1.0 / 0.0040 = 2.5 \times 10^2$. (b) The halved equation is $SO_2(g) + ½O_2(g) ⇌ SO_3(g)$, with expression $[SO_3] / ([SO_2][O_2]^{½})$. Substituting: 1.0 / (0.20 × √0.10) = 1.0 / (0.20 × 0.316) = 1.0 / 0.0632 = 15.8. (c) $\sqrt{(2.5 \times 10^2)} = 15.8$, confirming the rule. The same mixture returns two constants because each constant is defined by its own expression, and the halved expression raises the concentrations to half the powers.

B3. (a) Adding gives 2A(g) ⇌ C(g) + 2D(g); the intermediate is B, produced in step 1 and consumed in step 2. (b) $K = K_1 \times K_2 = 4.0 \times 0.50 = 2.0$. (c) The step expressions are $([B][C]) / [A]^2$ and $[D]^2 / [B]$.

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Multiplied: (([B][C]) / $[A]^2$) × ($[D]^2$ / [B]) = ([C]$[D]^2$) / $[A]^2$, with [B] cancelling top and bottom, which is exactly the expression of the overall reaction.

B4. (a) As written, step 2 produces B rather than consuming it, so adding would leave B on both sides doubled rather than cancelled; the target contains no B at all. (b) Reverse step 2: B(g) ⇌ C(g), with K = 1 / 0.10 = 10. (c) Adding A(g) ⇌ B(g) and B(g) ⇌ C(g) cancels B and gives A(g) ⇌ C(g), with K = 5.0 × 10 = 50. (d) Against the mixture: step 1 gives [B] / [A] = 0.50 / 0.10 = 5.0, as stated. Step 2 as written gives [B] / [C] = 0.50 / 5.0 = 0.10, as stated. The target gives [C] / [A] = 5.0 / 0.10 = 50, matching part (c) exactly. One mixture satisfies all three written forms at once, each with its own constant.

B5. (a) Reverse: 1 / 12 = 0.083. (b) Reverse and then double: $(1 / 12)^2 = 6.9 \times 10^{-3}$. (c) First manipulation, reversing: K becomes 1 / 12 = 0.083. Second manipulation, doubling every coefficient: K becomes $(0.083)^2 = 6.9 \times 10^{-3}$. (d) The constant 12 belongs to the original written equation, while the Q value was calculated from the doubled reverse expression; a Q and a K can only be compared when both belong to the same written form, so the comparison must use 6.9×10^{-3}.

B6. (a) Doubling squares the constant: $(2.1 \times 10^{-16})^2 = 4.4 \times 10^{-32}$. (b) Reversing the doubled reaction inverts its constant: $1 / (4.4 \times 10^{-32}) = 2.3 \times 10^{31}$. (c) The constant for the doubled equation is still minute, far below 1, so the equilibrium mixture is almost entirely N_2 and O_2 with a trace of NO. Doubling rewrote the same chemistry in a form whose expression squares every term; it moved the constant enormously on paper while the mixture it describes did not change at all.

C1. (a) Step 1 is used twice, in its forward direction. Step 2 is used once, in reverse. (b) Twice step 1 gives $2C(s) + 2O_2(g) \rightleftharpoons 2CO_2(g)$. Reversed step 2 gives $2CO_2(g) \rightleftharpoons 2CO(g) + O_2(g)$. Adding: the $2CO_2$ cancels, one O_2 cancels, leaving $2C(s) + O_2(g) \rightleftharpoons 2CO(g)$, the target. (c) $K = (K_1)^2 / K_2 = (2.0 \times 10^2)^2 / (4.0 \times 10^2) = (4.0 \times 10^4) / (4.0 \times 10^2) = 1.0 \times 10^2$. Step 1 doubled contributes its square; step 2 reversed contributes its reciprocal; the prepared constants are then multiplied. (d) Pure solids are omitted from K expressions because their concentration is constant and is folded into the constant (Topic 7.3). The manipulation rules act on the expressions as written, solid free, so reversing, squaring and multiplying work on K_1 and K_2 exactly as they would for any other steps.

C2. (a) $Kc = (1.57)^2 / (0.214 \times 0.214) = 2.46 / 0.0458 = 54$, as stated. (b) Reverse: K = 1 / 54 = 0.019. Against the mixture: $(0.214 \times 0.214) / (1.57)^2 = 0.0458 / 2.46 = 0.019$, agreeing. (c) Halved: $K = \sqrt{54} = 7.3$. Against the mixture: $1.57 / (\sqrt{0.214} \times \sqrt{0.214}) = 1.57 / 0.214 = 7.3$, agreeing. (d) From the original: reversing and doubling gives $(1 / 54)^2 = 3.4 \times 10^{-4}$. From part (b): doubling the reverse reaction squares its constant, using the unrounded value $(1 / 54)^2 = 3.4 \times 10^{-4}$. The agreement shows the manipulations commute and combine consistently: each written form of this one equilibrium has exactly one constant, reachable by any valid sequence of rules. (e) The constants from (b), 0.019, and from (d), 3.4×10^{-4}, are below 1. For their written equations, which consume

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HI, a below 1 constant means the equilibrium lies toward the reactants of that form: HI dominates the mixture, exactly as the forward constant of 54 already said from the other direction.

C3. (a) False. Multiplying the equation by 3 raises K to the third power: the exponents in the expression triple, so the constant is cubed, not tripled. (b) True. Reversing inverts the constant, 1 / 0.25 = 4.0, and a K above 1 for the reverse reaction means its products, the original reactants, dominate that written direction's equilibrium. (c) False. Adding reactions multiplies the constants: 2.0 × 5.0 = 10. The sum 7.0 belongs to no combination of the two expressions. (d) False. Halving the equation takes the square root of the constant: $\sqrt{(2.5 \times 10^2)} = 15.8$, about 16, not half of 250. (e) False. Q and K must belong to the same written form before they are compared. Halving the equation changes both the expression Q is calculated from and the constant it is compared with; keeping the old K against a new Q compares two different descriptions and can reverse the predicted direction.

Continue Revising

Topic 7.6 Revision Notes

Topic 7.6 Quiz: Properties of the Equilibrium Constant

Previous Worksheet: Topic 7.5 Magnitude of the Equilibrium Constant

Next Worksheet: Topic 7.7 Calculating Equilibrium Concentrations

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