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Topic 7.2: Direction of Reversible Reactions

Worksheet · AP Chemistry

UNIT 7 · EQUILIBRIUM

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How to Use This Worksheet

Work in order. Section A checks the decision rule: comparing the forward and reverse rates, from reactants only, from products only, and from mixtures. Section B works with one data set, $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$, approached from the product side: a table, rates, a second vessel, snapshots and a removal. Section C is exam style: an ammonia vessel charged with product only, a rate-time graph, and five claims to judge.

Reference facts. Net direction follows the larger rate: forward rate greater means reactants fall and products rise; equal rates mean no net change. An absent side has a rate of zero, so a one-sided start forces the opening direction. Concentration changes always follow the coefficients. No equilibrium constants are needed here. Useful values: the methanol system settles at $[CO] = 0.42$, $[H_2] = 0.84$ and $[CH_3OH] = 0.68$ mol L^{-1}.

Three habits protect every answer. Name the direction from the equation as written, never from habit. Compare the two rates, not the two head counts. And check every concentration change against the coefficients before trusting it.

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 is meant by the net direction of a reversible reaction. (b) State the rule that decides the net direction at any moment. (c) A system has equal forward and reverse rates but very different reactant and product concentrations. State its net direction, and explain.

A2. A reversible reaction is started with reactants only in a sealed vessel. (a) State the initial value of the reverse rate, and why. (b) State which concentrations rise and which fall at the start. (c) State why the forward rate is at its maximum at the start, and describe what happens to the gap between the two rates as the reaction proceeds.

A3. A reversible reaction is started with products only in a sealed vessel. (a) State the initial value of the forward rate, and why. (b) State the net direction at the start. (c) Describe how each rate changes as the system moves toward equilibrium, and why the net change slows down.

A4. In $2NO_2(g) \rightleftharpoons N_2O_4(g)$, readings show $[NO_2]$ falling by 0.20 mol L^{-1} over an interval while $[N_2O_4]$ rises by 0.10 mol L^{-1}. (a) State the net direction over the interval, as the equation is written. (b) Show that the two changes are consistent with the equation. (c) A second report claims $[NO_2]$ fell by 0.20 while $[N_2O_4]$ rose by 0.20 mol L^{-1} in the same vessel. State whether both reports can describe the same closed vessel, and why.

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A5. Two students describe the same flask. One writes the reaction as $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ and says the net reaction is reverse; the other writes it as $2NO_2(g) \rightleftharpoons N_2O_4(g)$ and says the net reaction is forward. (a) State what is physically happening to $[NO_2]$ in the flask. (b) Explain how both students can be right. (c) State what a direction claim always needs before it means anything.

Section B: Core Practice

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ is followed in a sealed vessel at constant temperature, charged with a product-rich mixture. Concentrations in mol L^{-1}:

Time (min)	$[CO]$	$[H_2]$	$[CH_3OH]$
0	0.20	0.40	0.90
2	0.30	0.60	0.80
4	0.36	0.72	0.74
6	0.40	0.80	0.70
8	0.42	0.84	0.68
10	0.42	0.84	0.68

B1. (a) State the net direction over the first 8 minutes, and the evidence in the table. (b) State the time by which equilibrium is reached, and the evidence. (c) State the equilibrium concentration of each species. (d) Calculate the change in concentration of each species between 0 and 8 minutes.

B2. (a) Show that the changes found in B1(d) obey the stoichiometry of the equation. (b) Calculate the average rate of disappearance of CH_3OH between 0 and 2 minutes. (c) Calculate the average rate of formation of CO between 6 and 8 minutes. (d) Calculate the average net rate of change of $[CH_3OH]$ between 8 and 10 minutes, and explain the value, given that CH_3OH is still reacting in both directions.

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B3. (a) At time zero, state which rate, forward or reverse, is larger, and explain the answer in terms of the concentrations. (b) Explain why the forward rate in this vessel is small at time zero but not zero. (c) Describe how each rate changes during the first 8 minutes, and the condition reached at 8 minutes. (d) At equilibrium the forward and reverse rates are each 0.015 mol L^{-1} min^{-1}, measured as the rate at which CH_3OH is formed and consumed. A student says $[CH_3OH]$ must therefore be falling at 0.015 mol L^{-1} min^{-1}. Correct the student.

B4. A second vessel at the same temperature is charged with [CO] = 1.10 mol L^{-1} and $[H_2]$ = 2.20 mol L^{-1}, and no CH_3OH. (a) State the net direction at the start, with a reason based on the rates. (b) Show that this vessel holds the same totals of carbon, hydrogen and oxygen per litre as the B1 vessel. (c) Predict the equilibrium concentrations in this vessel, and justify the prediction. (d) Calculate the change in [CO] and in $[H_2]$ needed to reach that equilibrium, and check the two changes against the equation.

B5. Snapshots are taken of $A_2(g) + B_2(g) \rightleftharpoons 2AB(g)$ in a sealed box. Snapshot 1 shows 6 A_2, 6 B_2 and 4 AB particles. Snapshot 2, taken later, shows 4 A_2, 4 B_2 and 8 AB. The equilibrium snapshot for this box shows 3 A_2, 3 B_2 and 10 AB. (a) State the net direction between the snapshots, with evidence. (b) Verify that snapshots 1 and 2 hold the same total number of A atoms and of B atoms. (c) State whether the box has reached equilibrium by snapshot 2, and describe what happens to the counts next.

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B6. The B1 vessel is at equilibrium when half of the CH_3OH is pumped out, dropping $[CH_3OH]$ instantly from 0.68 to 0.34 mol L^{-1}; [CO] and $[H_2]$ are unchanged at that instant. (a) State what happens to the reverse rate immediately, and why. (b) State what happens to the forward rate at that instant, and why. (c) State the net direction that follows. (d) Describe the new equilibrium: which way each concentration moves after the removal, and why $[CH_3OH]$ cannot climb back to 0.68 mol L^{-1}.

Section C: Exam Style

C1. Ammonia synthesis is written $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$. A sealed vessel is charged with NH_3 only, at $[NH_3]$ = 0.90 mol L^{-1}. It settles at $[NH_3]$ = 0.50, $[N_2]$ = 0.20 and $[H_2]$ = 0.60 mol L^{-1}. (a) Explain, in terms of rates, why the initial net change is toward reactants, giving the initial value of the forward rate. (b) Calculate the amount of NH_3 per litre that has decomposed by equilibrium, and check it against the N_2 and H_2 formed. (c) A second vessel at the same temperature starts with $[N_2]$ = 0.45 and $[H_2]$ = 1.35 mol L^{-1}, and no NH_3. Predict its equilibrium concentrations, justifying your answer with the total amounts of nitrogen and hydrogen in each vessel, and state the changes that take the second vessel there. (d) A student argues: "$[H_2]$ in the second vessel, 1.35 mol L^{-1}, is more than double the equilibrium value of 0.60 mol L^{-1}, so the second vessel must react in reverse." Judge the argument.

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C2. A rate-time graph is drawn for $2NO_2(g) \rightleftharpoons N_2O_4(g)$ in a sealed vessel charged with a mixture of both gases. Both rates are quoted as rates of change of $[N_2O_4]$: the forward reaction forms N_2O_4, the reverse reaction consumes it. The forward rate starts at 0.60 mol L^{-1} min^{-1} and falls steadily; the reverse rate starts at 0.30 mol L^{-1} min^{-1} and rises. The curves meet at 0.42 mol L^{-1} min^{-1} at t = 9 min and run level together after that. (a) State which rate is larger at t = 0, and what is happening to $[NO_2]$ and to $[N_2O_4]$ then. (b) State when equilibrium is reached, and the evidence. (c) Explain why the forward rate falls and the reverse rate rises during the first 9 minutes. (d) At t = 3 min the forward rate is 0.52 and the reverse rate is 0.36 mol L^{-1} min^{-1}. Calculate the net rate of change of $[N_2O_4]$ and of $[NO_2]$ at that moment.

C3. Judge each claim, supporting each verdict with the idea it depends on. (a) "If the concentration of products is higher than the concentration of reactants, the net reaction must be reverse." (b) "During a net forward reaction, the reverse reaction is not happening." (c) "Removing some product from an equilibrium mixture starts a net reverse reaction to replace it." (d) "A system approaching equilibrium overshoots it, swings back, and settles only after a few swings." (e) "Equal forward and reverse rates mean equal reactant and product concentrations."

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Answer Key

A1. (a) The direction of the overall change: which conversion, forward or reverse, is happening faster, and so which side is consumed net. (b) Compare the forward and reverse rates: the larger rate gives the net direction, and equal rates give no net change. (c) There is no net direction: the system is at equilibrium. Equal rates mean every forward conversion is balanced by a reverse one, so concentrations stay constant.

A2. (a) Zero: no product exists yet, so nothing can react back. (b) Reactant concentrations fall and product concentrations rise. (c) Reactant concentrations are highest at the start, so the forward rate starts at its maximum. As products accumulate, the reverse rate climbs from zero while the forward rate falls, narrowing the gap.

A3. (a) Zero. No reactants exist for the forward reaction to use. (b) Net reverse: products are converted back into reactants. (c) The reverse rate falls as products fall; the forward rate rises from zero as reactants accumulate. The gap narrows, so the net change slows toward zero.

A4. (a) Net forward, as written: NO_2 is the reactant here and is being consumed, while N_2O_4 is formed. (b) The equation consumes $2NO_2$ per N_2O_4 formed, so a fall of 0.20 mol L^{-1} in $[NO_2]$ pairs with a rise of half as much, 0.10, in $[N_2O_4]$. (c) No: a rise of 0.20 mol L^{-1} in $[N_2O_4]$ needs a fall of 0.40 in $[NO_2]$. The pair 0.20 and 0.20 breaks the ratio.

A5. (a) $[NO_2]$ is falling: NO_2 is consumed net and N_2O_4 is formed. (b) Forward and reverse are defined by the writing. With N_2O_4 on the left, forming N_2O_4 is right-to-left: reverse. With NO_2 on the left, the same change is left-to-right: forward. Each student describes the flask correctly, relative to their own writing. (c) The equation as written. A direction claim means nothing until the writing it refers to is fixed.

B1. (a) Net reverse: $[CH_3OH]$ falls while $[CO]$ and $[H_2]$ rise, so product is consumed net and reactants formed. (b) By 8 minutes: the readings at 8 and 10 minutes are identical for all three species. (c) $[CO]$ = 0.42 mol L^{-1}, $[H_2]$ = 0.84 mol L^{-1}, $[CH_3OH]$ = 0.68 mol L^{-1}. (d) CO: 0.42 − 0.20 = +0.22 mol L^{-1}. H_2: 0.84 − 0.40 = +0.44 mol L^{-1}. CH_3OH: 0.68 − 0.90 = −0.22 mol L^{-1}.

B2. (a) Read in reverse, the equation consumes CH_3OH and produces CO and H_2 in the ratio 1 : 2 : 1; the measured changes match exactly. (b) (0.90 − 0.80) ÷ (2 − 0) = 0.050 mol L^{-1} min^{-1}. (c) (0.42 − 0.40) ÷ (8 − 6) = 0.010 mol L^{-1} min^{-1}. (d) (0.68 − 0.68) ÷ (10 − 8) = 0 mol L^{-1} min^{-1}. Zero: the concentration does not change, because at equilibrium CH_3OH is formed and consumed at equal rates. The net change is the difference of two equal rates.

B3. (a) The reverse rate is larger. The vessel starts product-rich, $[CH_3OH]$ = 0.90 mol L^{-1}, so product particles react back often, while the reactants driving the forward rate are dilute. (b) The forward rate is not zero because both its reactants are present, CO at 0.20 and H_2 at 0.40 mol L^{-1}: it can run, just more slowly than the reverse. A rate is zero only when a species on its side is absent. (c) The

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reverse rate falls as [CH_3OH] falls; the forward rate rises as [CO] and [H_2] build up, until at 8 minutes the rates are equal. (d) The net rate of change is forward minus reverse: 0.015 − 0.015 = 0 mol L^{-1} min^{-1}. The value 0.015 is the rate at which CH_3OH is formed and, separately, consumed; concentration changes only by the difference.

B4. (a) Net forward: with no CH_3OH present the reverse rate is zero, while CO and H_2 at high concentrations put the forward rate at its maximum. (b) Carbon: B1 holds 0.20 from CO plus 0.90 from CH_3OH, total 1.10 mol L^{-1}; this vessel holds 1.10 from CO. Oxygen: B1 holds 0.20 plus 0.90 = 1.10; this vessel holds 1.10. Hydrogen atoms: B1 holds 2 × 0.40 + 4 × 0.90 = 4.40; this vessel holds 2 × 2.20 = 4.40. All three totals match. (c) The same equilibrium as B1: [CO] = 0.42, [H_2] = 0.84, [CH_3OH] = 0.68 mol L^{-1}, because the same reaction at the same temperature with the same totals settles at the same composition from either side. (d) [CO]: 0.42 − 1.10 = −0.68 mol L^{-1}. [H_2]: 0.84 − 2.20 = −1.36 mol L^{-1}, exactly twice the CO change, and the CH_3OH formed, +0.68, matches the CO consumed.

B5. (a) Net forward: A_2 and B_2 counts fell while the AB count rose, so reactants are consumed net and product formed. (b) A atoms: snapshot 1, 2 × 6 + 4 = 16; snapshot 2, 2 × 4 + 8 = 16. B atoms: the same two totals, 16 and 16. Both conserved. (c) No. Equilibrium counts are 3, 3 and 10; snapshot 2 shows 4, 4 and 8. Net forward reaction continues until the counts reach 3, 3 and 10.

B6. (a) The reverse rate falls immediately, because it is driven by [CH_3OH], just halved. (b) The forward rate is unchanged at that instant: [CO] and [H_2], which drive it, were untouched. (c) Net forward: the forward rate is now larger. (d) [CO] and [H_2] fall and [CH_3OH] rises from 0.34 mol L^{-1} until the rates are equal again. [CH_3OH] cannot regain 0.68 mol L^{-1}: the vessel now holds only 0.42 + 0.34 = 0.76 mol L^{-1} of carbon, and some must remain as CO.

C1. (a) The vessel holds NH_3 only, so the forward rate starts at zero: there is no N_2 or H_2 to react. The reverse reaction has its reactant at full concentration, so its rate is at maximum. With the reverse rate larger, net change runs toward reactants until the forward rate catches up. (b) NH_3 decomposed: 0.90 − 0.50 = 0.40 mol L^{-1}. Check: read in reverse, the equation turns $2NH_3$ into N_2 and $3H_2$, so 0.40 mol L^{-1} of NH_3 forms 0.20 of N_2 and 0.60 of H_2, matching the equilibrium values. (c) Nitrogen totals: vessel 1, 0.90 mol L^{-1}; vessel 2, 2 × 0.45 = 0.90. Hydrogen totals: vessel 1, 3 × 0.90 = 2.70; vessel 2, 2 × 1.35 = 2.70. Same totals, same temperature: vessel 2 reaches the same equilibrium, [NH_3] = 0.50, [N_2] = 0.20, [H_2] = 0.60 mol L^{-1}, by net forward reaction: [N_2] falls by 0.25, [H_2] by 0.75 and [NH_3] rises by 0.50 mol L^{-1}, in the 1 : 3 : 2 ratio. (d) Wrong. Direction is set by comparing the two rates, not by comparing one concentration with its equilibrium value. Vessel 2 contains no NH_3, so its reverse rate is zero: the only net direction is forward, and the excess H_2 is consumed as NH_3 forms.

C2. (a) The forward rate is larger, 0.60 against 0.30 mol L^{-1} min^{-1}, so the net reaction is forward: [N_2O_4] rises, [NO_2] falls. (b) Equilibrium is reached at t = 9 min, where the curves meet; after that the rates stay equal and level. (c) The forward rate falls because [NO_2] falls as NO_2 is consumed, so

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its particles collide less often. The reverse rate rises because $[N_2O_4]$ climbs, so more N_2O_4 is present to break down. (d) Net rate for N_2O_4: 0.52 − 0.36 = +0.16 mol L^{-1} min^{-1}, so $[N_2O_4]$ rises at 0.16 mol L^{-1} min^{-1}. Each N_2O_4 formed consumes $2NO_2$, so $[NO_2]$ falls at 2 × 0.16 = 0.32 mol L^{-1} min^{-1}.

C3. (a) False. Direction is decided by comparing the rates, equivalently by comparing the mixture with the equilibrium composition. $[H_2]$ = $[I_2]$ = 0.50 mol L^{-1} with [HI] = 1.00 mol L^{-1} is product-rich yet short of equilibrium, [HI] = 1.56 mol L^{-1}, and runs net forward. (b) False. The reverse reaction runs whenever any product is present; net forward means the forward rate is larger, not that the reverse rate is zero. (c) False. Removing product lowers the reverse rate, so the forward rate becomes the larger one and net forward reaction replaces the lost product. (d) False. Approaching equilibrium, the winning rate falls and the losing rate rises; they meet and net change stops. No overshoot, no swinging. (e) False. Equilibrium needs equal rates, not equal concentrations: the methanol equilibrium of Section B sits at [CO] = 0.42, $[H_2]$ = 0.84 and $[CH_3OH]$ = 0.68 mol L^{-1}, three different values.

Continue Revising

Topic 7.2 Revision Notes

Topic 7.2 Quiz: Direction of Reversible Reactions

Previous Worksheet: Topic 7.1 Introduction to Equilibrium

Next Worksheet: Topic 7.3 Reaction Quotient and Equilibrium Constant

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