

Gas equilibrium: quotient, extent and physical solutions

Chemistry · Year 12 · Exceeding

Use the worked examples and teaching notes to guide the lesson. Each practice answer and its full working appear beside the question.

Take the time you need. Complete each phase and revisit any step you cannot yet explain.

Get ready

Learning goal

Model and critically evaluate a gas equilibrium using atom conservation, the reaction quotient and physically valid ICE solutions.

- Construct the quotient from the balanced equation and justify net direction.
- Solve forward and reverse ICE calculations, rejecting inadmissible roots.
- Test rather than assume a small-x approximation.
- Distinguish immediate changes from new equilibrium after volume or temperature changes.
- Evaluate claims and transformed equations using conservation and equilibrium checks.

The idea in context

A compressed nitrogen-oxide mixture becomes more concentrated immediately, then reacts in the opposite direction. Can its final nitrogen dioxide concentration still exceed its original value?

Before you begin

Coefficients, concentration and reaction extent

Concentration equals amount divided by volume. For $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$ at fixed volume, consuming x concentration units of N_2O_4 forms $2x$ of NO_2 . Atom counts are conserved; molecule counts need not be.

reaction extent x : The concentration change assigned to one N_2O_4 coefficient in this fixed-volume ICE calculation.

coefficient: The number of formula units; it multiplies each atom count without changing the substance.

concentration: Amount of a substance divided by its volume; here measured in moles per litre, mol L^{-1} .

Watch the prerequisite 1

Why does $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ use coefficient two?

Step 1

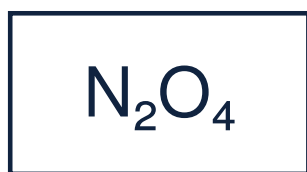
Before: One N_2O_4 molecule.

Action: Count subscripts.

After: Two nitrogen atoms and four oxygen atoms.

Why: A subscript gives atom count in one molecule.

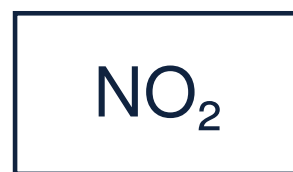
One molecule



Two molecules



+



N: 2 O: 4

N: 1 + 1 O: 2 + 2

Atom totals match; molecule counts differ.

Coefficients conserve atoms

One dinitrogen tetroxide composition token corresponds to two nitrogen dioxide tokens. Each side has two nitrogen atoms and four oxygen atoms. Molecule counts differ. Tokens show composition, not molecular geometry.

Step 2

Before: One NO_2 contains one nitrogen and two oxygen atoms.

Action: Use two NO_2 molecules.

After: Nitrogen: $2 \times 1 = 2$. Oxygen: $2 \times 2 = 4$.

Why: The coefficient multiplies every atom count in the formula; formulas remain unchanged.

Both sides contain two nitrogen and four oxygen atoms. Changing NO_2 to another formula changes the substance.

Watch the prerequisite 2

A sample contains 0.100 mol in 0.500 L. Find its concentration, then find the immediate concentration if its volume doubles without reaction.

Step 1

Before: Concentration is amount per litre.

Action: Write $c = n/V$.

After: $n = 0.100 \text{ mol}$; $V = 0.500 \text{ L}$

Why: The numerator is amount and the denominator is volume; use the stated litre units.

Step 2

Before: $c = n/V$

Action: Substitute the amount and volume.

After: $c = 0.100/0.500 = 0.200 \text{ mol L}^{-1}$

Why: Dividing by half a litre gives the amount in one litre.

$$c = n/V$$

$$c = 0.100 \text{ mol} \div 0.500 \text{ L}$$

$$c = 0.200 \text{ mol L}^{-1}$$

Amount divided by volume

$$c = n/V \quad c = 0.100 \text{ mol} \div 0.500 \text{ L} \quad c = 0.200 \text{ mol L}^{-1}$$

Step 3

Before: Amount remains 0.100 mol.

Action: Double the volume.

After: New volume = $2 \times 0.500 = 1.000 \text{ L}$

Why: This immediate dilution changes volume, not the amount of reacting atoms.

Step 4

Before: $c = n/V$; $n = 0.100$; $V = 1.000$

Action: Divide the unchanged amount by the new volume.

After: $c = 0.100/1.000 = 0.100 \text{ mol L}^{-1}$

Why: Twice the volume gives half the concentration before any chemical adjustment.

Step 5

Before: Initial and new amounts should match.

Action: Multiply each concentration by its own volume.

After: $0.200 \times 0.500 = 0.100$; $0.100 \times 1.000 = 0.100 \text{ mol}$

Why: Both states contain the same amount.

Initially 0.200 mol L^{-1} ; immediately after doubling volume, 0.100 mol L^{-1} .

Complete the missing step 1

Complete the counts for $3\text{N}_2\text{O}_4$ and 6NO_2 . Do they contain matching totals?

Hint 1: Use the coefficient to multiply each subscript.

Hint 2: For $3\text{N}_2\text{O}_4$, nitrogen count is three groups of two.

Hint 3: Find both oxygen totals, then compare each element separately.

$3\text{N}_2\text{O}_4$: $\text{N} = 3 \times 2 = 6$; $\text{O} = 3 \times 4 = 12$. 6NO_2 : $\text{N} = 6 \times 1 = 6$; $\text{O} = 6 \times 2 = 12$. Atom totals match, although molecule counts differ.

Complete the missing step 2

Complete $c = \underline{\quad}/\underline{\quad}$: amount is 0.120 mol and volume is 0.600 L . What happens immediately to c if that volume halves without reaction?

Hint 1: Put amount above volume.

Hint 2: Use $0.120/0.600$ for the original concentration.

Hint 3: Keep amount unchanged and use the halved volume 0.300 L for the new division.

$c = n/V = 0.120/0.600 = 0.200 \text{ mol L}^{-1}$. Halved volume = 0.300 L . New $c = 0.120/0.300 = 0.400 \text{ mol L}^{-1}$, twice the initial value. Check: $0.400 \times 0.300 = 0.120 \text{ mol}$.

Try a fresh question 1

An extent of $0.0200 \text{ mol L}^{-1} \text{ N}_2\text{O}_4$ is consumed at fixed volume. State both concentration changes and check atom conservation.

Hint 1: Use the balanced one-to-two relationship.

Hint 2: Set the N_2O_4 change to minus the stated extent.

Hint 3: NO_2 forms at twice that extent. Check two times the reactant change plus the product change.

$\Delta[\text{N}_2\text{O}_4] = -0.0200 \text{ mol L}^{-1}$; $\Delta[\text{NO}_2] = +0.0400 \text{ mol L}^{-1}$. Nitrogen change: $2 \times (-0.0200) + 0.0400 = 0$; oxygen change is twice that, also zero.

Try a fresh question 2

A sample contains 0.300 mol in 0.750 L. Find c , then its immediate concentration after volume triples without reaction.

Hint 1: Use $c = n/V$ with the stated units.

Hint 2: Divide 0.300 by 0.750 first.

Hint 3: Tripling the volume keeps amount unchanged and divides the concentration by three.

$c = 0.300/0.750 = 0.400 \text{ mol L}^{-1}$. New volume = $3 \times 0.750 = 2.250 \text{ L}$. New $c = 0.300/2.250 = 0.133333... \text{ mol L}^{-1}$, one-third the original concentration. Check amount: $0.133333... \times 2.250 = 0.300 \text{ mol}$.

Equal operations, bracket expansion and quadratic roots

Apply the same operation to both sides. Expand the square of a difference with its middle term. A quadratic may have two mathematical roots; concentrations and direction determine which are physical.

physical root: A mathematical solution that also obeys nonnegative concentrations, stoichiometry and the stated direction of change.

Watch the prerequisite 1

Solve $2x - 10 = 6$ using equal operations.

Step 1

Before: $2x - 10 = 6$

Action: Add ten to both sides.

After: $2x - 10 + 10 = 6 + 10$; $2x = 16$

Why: The marked opposite terms sum to zero.

$$\begin{array}{rcl} 2x - 10 & = & 6 \\ +10 & & +10 \\ \hline \end{array}$$

$$2x \quad \quad \quad \cancel{-10} \quad \quad \quad \cancel{+10} \quad \quad = \quad 16$$

Opposite terms sum to zero.

$$2x \quad \quad = \quad \quad 16$$

Apply +10 to both sides

$2x - 10$ equals 6. Apply +10 to each side. Result: $2x$ equals 16. The marked opposite terms sum to zero.

Step 2

Before: $2x = 16$

Action: Divide both sides by two.

After: $2x/2 = 16/2$; $x = 8$

Why: Matching factors two reduce to one. Check: $2 \times 8 - 10 = 6$.

$x = 8$; each equal operation preserves equality.

Complete the missing step 1

Rearrange $0.100 - 0.200x = 4x^2$ into a quadratic equal to zero. Show the operation on both sides.

Hint 1: Preserve equality while collecting the quadratic terms.

Hint 2: Add $0.200x$ to both sides; the opposite x terms sum to zero.

Hint 3: Now subtract 0.100 from both sides and write the quadratic expression on the left.

Add $0.200x$ to both sides: $0.100 - 0.200x + 0.200x = 4x^2 + 0.200x$, so $0.100 = 4x^2 + 0.200x$. Subtract 0.100 from both sides: $0 = 4x^2 + 0.200x - 0.100$.

Try a fresh question 1

Expand $(0.400 - 2x)^2$ and collect terms in $(0.400 - 2x)^2 = 0.200(0.100 + x)$.

Hint 1: Use the square of a difference, including its middle term.

Hint 2: Expand both sides: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$.

Hint 3: Subtract the entire right expression from both sides, then combine like terms.

$(u - v)^2 = u^2 - 2uv + v^2$. Here the left becomes $0.160 - 1.600x + 4x^2$; the right is $0.0200 + 0.200x$. Subtract the right expression from both sides: $4x^2 - 1.800x + 0.140 = 0$.

Starting-point question 1

Count nitrogen and oxygen atoms in 2NO_2 .

Answer and working

Two nitrogen atoms and four oxygen atoms.

Starting-point question 2

An amount 0.100 mol occupies 0.500 L. Find concentration.

Answer and working

$0.100/0.500 = 0.200 \text{ mol L}^{-1}$.

Starting-point question 3

What equal operation isolates y in $y - 3 = 8$?

Answer and working

Add three to both sides; $y = 11$.

Starting-point question 4

Expand $(u - v)^2$.

Answer and working

$u^2 - 2uv + v^2$.

Watch — I do

Count atoms, then construct the quotient

Use $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$. Square the product concentration because its coefficient is two. In this lesson K means the classroom concentration equilibrium constant K with subscript c; Q is the corresponding reaction quotient at the current composition. Values are illustrative training data, not measured nitrogen-oxide constants.

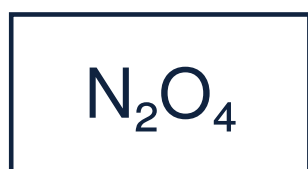
$$K = [\text{NO}_2]^2 / [\text{N}_2\text{O}_4]$$

$Q < K$: net forward change

$Q > K$: net reverse change

$Q = K$: equilibrium

One molecule



Two molecules



+



N: 2 O: 4

N: 1 + 1 O: 2 + 2

Atom totals match; molecule counts differ.

Coefficients conserve atoms

One dinitrogen tetroxide composition token corresponds to two nitrogen dioxide tokens. Each side has two nitrogen atoms and four oxygen atoms. Molecule counts differ. Tokens show composition, not molecular geometry.

Track the same extent through both species

At fixed volume, an ICE table lists initial, change and equilibrium concentrations. For forward change use $-x$ and $+2x$; for reverse change use $+x$ and $-2x$. Choose the direction by Q versus K before defining x.

Forward: $[\text{N}_2\text{O}_4] = A - x$; $[\text{NO}_2] = B + 2x$

Reverse: $[\text{N}_2\text{O}_4] = A + x$; $[\text{NO}_2] = B - 2x$

Initial: $\text{N}_2\text{O}_4 = \text{A}; \quad \text{NO}_2 = \text{B}$

Forward: $-\text{x} \quad +2\text{x}$

Equilibrium: $\text{A} - \text{x} \quad \text{B} + 2\text{x}$

Keep the coefficient in every change

Initial: $\text{N}_2\text{O}_4 = \text{A}; \quad \text{NO}_2 = \text{B}$ Forward: $-\text{x} \quad +2\text{x}$ Equilibrium: $\text{A} - \text{x} \quad \text{B} + 2\text{x}$

Solve and test the root

For $ax^2 + bx + c = 0$ with $a \neq 0$, use the quadratic formula below. In an equilibrium calculation, reject roots that violate the concentration bounds or the defined direction. Substitute valid concentrations back into K and check atom conservation.

$$r = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Nonnegative concentrations

Correct stoichiometric change

Quotient equals supplied K

Initial atom inventory preserved

A mathematical root must also be physical

Nonnegative concentrations Correct stoichiometric change Quotient equals supplied K Initial atom inventory preserved

Test a shortcut

Neglecting x in $\text{A} - x$ is a conditional approximation. Here a 5% depletion screen is a stated modelling tolerance, not a universal accuracy guarantee. Test x/A after calculating the estimate, and use the complete equation if the screen fails.

Approximate only if justified: $x/\text{A} \times 100\% < 5\%$

$$x = 0.158; A = 0.500: 31.6\%$$

$$x = 0.005; A = 0.500: 1.00\%$$

Use the full equation when needed

Compare estimated depletion

$$x = 0.158; A = 0.500: 31.6\% \quad x = 0.005; A = 0.500: 1.00\% \quad \text{Use the full equation when needed}$$

Distinguish the immediate state from equilibrium

A rapid volume change rescales concentrations before appreciable reaction. Q changes, then reaction adjusts composition until Q equals K. At fixed temperature K stays unchanged. A temperature change can change K. A catalyst does not change the equilibrium constant or equilibrium composition.

Halve volume: each concentration doubles

Q after compression = 2Q before compression

Before: N_2O_4 0.200; NO_2 0.200

Immediate: N_2O_4 0.400; NO_2 0.400

Later: N_2O_4 0.450; NO_2 0.300

Compression and later adjustment

Before: N_2O_4 0.200; NO_2 0.200 Immediate: N_2O_4 0.400; NO_2 0.400 Later: N_2O_4 0.450; NO_2 0.300

Check claims using more than one condition

Closed fixed-volume atom conservation gives $2[\text{N}_2\text{O}_4] + [\text{NO}_2]$ equal to its initial value. Satisfying K alone does not prove that a proposed final composition came from that starting mixture. Reversing the balanced equation inverts K; doubling it squares K.

K for reverse equation = $1/K$

K for doubled equation = K^2

$$\text{Original: } [\text{NO}_2]^2/[\text{N}_2\text{O}_4] = K$$

$$\text{Reverse: } [\text{N}_2\text{O}_4]/[\text{NO}_2]^2 = 1/K$$

$$\text{Doubled: } [\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2 = K^2$$

Rewrite the expression before the constant

Original: $[\text{NO}_2]^2/[\text{N}_2\text{O}_4] = K$ Reverse: $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2 = 1/K$ Doubled: $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2 = K^2$

Watch — worked models

Follow the model

At the supplied temperature $K = 0.200$. $[\text{N}_2\text{O}_4] = 0.300$; $[\text{NO}_2] = 0.200$. Predict net reaction direction.

Step 1

Before: Current concentrations may not be equilibrium values.

Action: Use Q to describe the present state.

$$\text{After: } Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$$

Why: K is the equilibrium reference at this temperature.

Step 2

$$\text{Before: } Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$$

Action: Square product concentration, then divide.

$$\text{After: } Q = (0.200)^2/0.300 = 0.133$$

Why: The coefficient two becomes an exponent.

Step 3

$$\text{Before: } Q = 0.133; K = 0.200$$

Action: Compare the two values.

After: Net change is rightwards.

Why: Q below K needs a larger ratio; Q above K needs a smaller ratio.

Net rightwards; K remains 0.200.

Follow the model

At the supplied temperature $K = 0.200$. $[N_2O_4] = 0.200$; $[NO_2] = 0.400$. Predict net reaction direction.

Step 1

Before: Current concentrations may not be equilibrium values.

Action: Use Q to describe the present state.

After: $Q = [NO_2]^2/[N_2O_4]$

Why: K is the equilibrium reference at this temperature.

Step 2

Before: $Q = [NO_2]^2/[N_2O_4]$

Action: Square product concentration, then divide.

After: $Q = (0.400)^2/0.200 = 0.800$

Why: The coefficient two becomes an exponent.

Step 3

Before: $Q = 0.800$; $K = 0.200$

Action: Compare the two values.

After: Net change is leftwards.

Why: Q below K needs a larger ratio; Q above K needs a smaller ratio.

Net leftwards; K remains 0.200.

Follow the model

Initially $[N_2O_4] = 0.500$ and $[NO_2] = 0$. $K = 0.200$. Find both equilibrium concentrations.

Step 1

Before: Initial $Q = 0^2/0.500 = 0$.

Action: Compare with $K = 0.200$.

After: $Q < K$, so net forward change.

Why: Reactant is consumed; product forms.

Step 2

Before: Define x as concentration of N_2O_4 consumed.

Action: Apply the balanced coefficients.

After: $[\text{N}_2\text{O}_4] = 0.500 - x$; $[\text{NO}_2] = 2x$

Why: One reactant unit gives two product units.

Initial: N_2O_4 0.500; NO_2 0

Change: N_2O_4 $-x$; NO_2 $+2x$

Equilibrium: $0.500 - x$; $2x$

Initial, change and equilibrium

Initial: N_2O_4 0.500; NO_2 0 Change: N_2O_4 $-x$; NO_2 $+2x$ Equilibrium: $0.500 - x$; $2x$

Step 3

Before: Concentrations cannot be negative.

Action: Set the physical range.

After: $0 \leq x \leq 0.500$

Why: The product concentration is $2x$ and reactant is $0.500 - x$.

Step 4

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute the equilibrium expressions.

After: $0.200 = (2x)^2/(0.500 - x)$

Why: Square the whole product expression, including coefficient two.

Step 5

Before: $0.200 = 4x^2/(0.500 - x)$

Action: Multiply both sides by $0.500 - x$.

After: $0.200(0.500 - x) = 4x^2$

Why: The denominator factor reduces to one; $x = 0.500$ cannot satisfy finite K.

$$0.200 = 4x^2/(0.500 - x)$$

$\times(0.500 - x)$ on both sides

$$0.200(0.500 - x) = 4x^2$$

Multiply both sides by the denominator

$$0.200 = 4x^2/(0.500 - x) \times (0.500 - x) \text{ on both sides } 0.200(0.500 - x) = 4x^2$$

Step 6

Before: $0.200(0.500 - x) = 4x^2$

Action: Distribute 0.200 across the bracket.

After: $0.100 - 0.200x = 4x^2$

Why: Multiply each term in the bracket.

Step 7

Before: $0.100 - 0.200x = 4x^2$

Action: Add $0.200x$ to both sides.

After: $0.100 = 4x^2 + 0.200x$

Why: The opposite x terms sum to zero.

$$\begin{array}{rcl} 0.100 - 0.200x & = & 4x^2 \\ +0.200x & & +0.200x \\ \hline 0.100 & \cancel{-0.200x} \quad \cancel{+0.200x} = & 4x^2 + 0.200x \end{array}$$

Opposite terms sum to zero.

$$0.100 = 4x^2 + 0.200x$$

Apply $+0.200x$ to both sides

0.100 - 0.200x equals $4x^2$. Apply +0.200x to each side. Result: 0.100 equals $4x^2 + 0.200x$. The marked opposite terms sum to zero.

Step 8

Before: $0.100 = 4x^2 + 0.200x$

Action: Subtract 0.100 from both sides.

After: $4x^2 + 0.200x - 0.100 = 0$

Why: Read the same equality with the quadratic on the left.

$$\begin{array}{rcl}
 0.100 & = & 4x^2 + 0.200x \\
 -0.100 & & -0.100 \\
 \hline
 \cancel{0.100} - \cancel{0.100} & = & 4x^2 + 0.200x - 0.100
 \end{array}$$

Opposite terms sum to zero.

$$0 = 4x^2 + 0.200x - 0.100$$

Apply -0.100 to both sides

0.100 equals $4x^2 + 0.200x$. Apply -0.100 to each side. Result: 0 equals $4x^2 + 0.200x - 0.100$. The marked opposite terms sum to zero.

Step 9

Before: $4x^2 + 0.200x - 0.100 = 0$

Action: Identify quadratic coefficients.

After: $a = 4$; $b = 0.200$; $c = -0.100$

Why: Include the negative sign in c .

Step 10

Before: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Action: Substitute all coefficients.

After: $x = \frac{-0.200 \pm \sqrt{(0.0400 + 1.600)}}{8}$

Why: Subtracting the negative product adds 1.600.

Step 11

Before: Discriminant = 1.640.

Action: Calculate both signs.

After: $x = 0.135078$ or $x = -0.185078$

Why: Keep guard digits until final concentrations.

Step 12

Before: Physical range: $0 \leq x \leq 0.500$.

Action: Reject the negative root.

After: $x = 0.135078$

Why: A negative extent would produce negative NO_2 from an initial zero amount.

Step 13

Before: $[\text{N}_2\text{O}_4] = 0.500 - x$; $[\text{NO}_2] = 2x$

Action: Substitute the valid extent.

After: $[\text{N}_2\text{O}_4] = 0.364922$; $[\text{NO}_2] = 0.270156$

Why: Report approximately 0.365 and 0.270 mol L⁻¹ to three significant figures.

Step 14

Before: Proposed concentrations 0.364922 and 0.270156.

Action: Check quotient and atoms.

After: $0.270156^2/0.364922 \approx 0.200$; $2 \times 0.364922 + 0.270156 = 1.000$

Why: Both the equilibrium ratio and the initial nitrogen-atom inventory agree.

$[\text{N}_2\text{O}_4] \approx 0.365 \text{ mol L}^{-1}$; $[\text{NO}_2] \approx 0.270 \text{ mol L}^{-1}$.

Follow the model

Initially $[\text{N}_2\text{O}_4] = 0.100$ and $[\text{NO}_2] = 0.400$. $K = 0.200$. Find equilibrium concentrations.

Step 1

Before: $Q = 0.400^2/0.100 = 1.60$.

Action: Compare with K .

After: $Q > 0.200$; net reverse change.

Why: Define x as N_2O_4 formed.

Step 2

Before: One N_2O_4 forms from two NO_2 .

Action: Write reverse changes.

After: $[\text{N}_2\text{O}_4] = 0.100 + x$; $[\text{NO}_2] = 0.400 - 2x$

Why: The range is $0 \leq x \leq 0.200$.

Step 3

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute and multiply both sides by $0.100 + x$.

After: $(0.400 - 2x)^2 = 0.200(0.100 + x)$

Why: The whole squared bracket must be expanded.

Step 4

Before: $(u - v)^2 = u^2 - 2uv + v^2$

Action: Expand both sides.

After: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$

Why: The middle term includes twice 0.400 times 2x.

$$\begin{aligned}(0.400 - 2x)^2 \\&= 0.400^2 - 2 \times 0.400 \times 2x + (2x)^2 \\&= 0.160 - 1.600x + 4x^2\end{aligned}$$

Expand all three square terms

$$(0.400 - 2x)^2 = 0.400^2 - 2 \times 0.400 \times 2x + (2x)^2 = 0.160 - 1.600x + 4x^2$$

Step 5

Before: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$

Action: Subtract 0.0200 and 0.200x from both sides.

After: $4x^2 - 1.800x + 0.140 = 0$

Why: Equal operations preserve the equation.

Step 6

Before: $a = 4$; $b = -1.800$; $c = 0.140$

Action: Use both signs of the quadratic formula.

After: $x = (1.800 \pm \sqrt{(3.240 - 2.240)})/8$; $x = 0.100$ or 0.350

Why: The discriminant is 1.000.

Step 7

Before: x must be at most 0.200.

Action: Reject $x = 0.350$.

After: $x = 0.100$

Why: The other root gives $[\text{NO}_2] = 0.400 - 0.700 = -0.300$, impossible.

Step 8

Before: $x = 0.100$

Action: Calculate and check both concentrations.

After: $[\text{N}_2\text{O}_4] = 0.200$; $[\text{NO}_2] = 0.200$; $Q = 0.200$

Why: $2 \times 0.200 + 0.200 = 0.600$, matching $2 \times 0.100 + 0.400$.

Both equilibrium concentrations are 0.200 mol L^{-1} .

Follow the model

Initially $[\text{N}_2\text{O}_4] = 0.500$ and $[\text{NO}_2] = 0$; supplied $K = 0.2$. Test neglecting x using a 5% depletion screen.

Step 1

Before: $K = 4x^2/(0.500 - x)$

Action: Assume x is small relative to 0.500.

After: $K \approx 4x^2/0.500$

Why: This is a hypothesis to test, not an established equality.

Step 2

Before: $K \approx 4x^2/0.500$

Action: Multiply by 0.500, divide by four, then take the nonnegative square root.

After: $x \approx \sqrt{(0.2 \times 0.500/4)} = 0.158114$

Why: The defined forward extent is nonnegative.

Step 3

Before: x estimate 0.158114.

Action: Calculate the estimated depletion fraction.

After: $x/0.500 \times 100\% = 31.62\%$

Why: Compare this with the stated 5% screen.

Step 4

Before: Depletion 31.62%.

Action: Decide whether the shortcut is suitable.

After: The screen fails; use the full quadratic.

Why: The full solution gives $x = 0.13507811$.

Estimated depletion 31.62%; reject the approximation.

Follow the model

Initially $[\text{N}_2\text{O}_4] = 0.500$ and $[\text{NO}_2] = 0$; supplied $K = 0.0002$. Test neglecting x using a 5% depletion screen.

Step 1

Before: $K = 4x^2/(0.500 - x)$

Action: Assume x is small relative to 0.500.

After: $K \approx 4x^2/0.500$

Why: This is a hypothesis to test, not an established equality.

Step 2

Before: $K \approx 4x^2/0.500$

Action: Multiply by 0.500, divide by four, then take the nonnegative square root.

After: $x \approx \sqrt{(0.0002 \times 0.500/4)} = 0.005000$

Why: The defined forward extent is nonnegative.

Step 3

Before: x estimate 0.005000.

Action: Calculate the estimated depletion fraction.

After: $x/0.500 \times 100\% = 1.00\%$

Why: Compare this with the stated 5% screen.

Step 4

Before: Depletion 1.00%.

Action: Decide whether the shortcut is suitable.

After: The screen passes; assess the required numerical precision too.

Why: The full solution gives $x = 0.00497506$.

Step 5

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 6

Before: $[\text{NO}_2] = 0$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0^2 = 0$

Why: Square the whole concentration; do not multiply it by two.

Step 7

Before: Product square 0; reactant 0.5

Action: Divide the product square by reactant concentration.

After: $Q = 0/0.5 = 0$

Why: Use the current values to calculate Q.

Step 8

Before: $Q = 0$; $K = 0.0002$

Action: Compare Q with the reference at this temperature.

After: Q is below K: net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

Step 9

Before: The quotient determines the net reaction direction.

Action: Define nonnegative x as N_2O_4 consumed.

After: $[\text{N}_2\text{O}_4] = 0.5 - x$; $[\text{NO}_2] = 0 + 2x$

Why: The balanced equation gives one-to-two concentration changes.

Step 10

Before: Every final concentration must be nonnegative.

Action: Set the extent bounds.

After: $0 \leq x \leq 0.5$

Why: Reject roots that violate these bounds or give zero denominator at finite K.

Step 11

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute both equilibrium expressions.

After: $0.0002 = (0 + 2x)^2/(0.5 - x)$

Why: Square the entire numerator bracket.

Step 12

Before: $0.0002 = (0 + 2x)^2 / (0.5 - x)$

Action: Multiply both sides by $0.5 - x$.

After: $0.0002(0.5 - x) = (0 + 2x)^2$

Why: The denominator factor reduces to one.

Step 13

Before: $(0 + 2x)^2$

Action: Expand the square, including its middle term.

After: $0 + 0x + 4x^2$

Why: Use $u^2 \pm 2uv + v^2$; here v is $2x$.

Step 14

Before: $0.0002(0.5 - x)$

Action: Distribute K to both terms.

After: $0.0001 - 0.0002x$

Why: Both the constant term and the x term are multiplied by K .

Step 15

Before: $0 + 0x + 4x^2 = 0.0001 - 0.0002x$

Action: Subtract 0.0001 from both sides.

After: $-0.0001 + 0x + 4x^2 = -0.0002x$

Why: The matching constant on the right sums to zero.

Step 16

Before: The right side contains $-0.0002x$.

Action: Add $0.0002x$ on both sides.

After: $4x^2 + 0.0002x - 0.0001 = 0$

Why: Combine the x coefficients; the opposite right-side x terms sum to zero.

Step 17

Before: $4x^2 + 0.0002x - 0.0001 = 0$

Action: Read the quadratic coefficients.

After: $a = 4$; $b = 0.0002$; $c = -0.0001$

Why: Retain each coefficient sign.

Step 18

Before: Discriminant = $b^2 - 4ac$

Action: Substitute and calculate.

After: $(0.0002)^2 - 4 \times 4 \times (-0.0001) = 0.00160004$

Why: Bracket a negative coefficient when substituting.

Step 19

Before: $x = (-b \pm \sqrt{b^2 - 4ac})/(2a)$

Action: Substitute into the quadratic formula.

After: $x = (-(0.0002) \pm \sqrt{0.00160004})/8$

Why: Calculate both signs; the denominator is two times four.

Step 20

Before: Both signs of the formula are required.

Action: Calculate both numerical roots.

After: $x = 0.00497506$ or -0.00502506

Why: Use the physical constraints to choose the valid root.

Step 21

Before: $0 \leq x \leq 0.5$

Action: Reject $x = -0.00502506$.

After: Use $x = 0.00497506$

Why: The rejected value violates the extent bounds and gives a negative species concentration.

Step 22

Before: Use the valid extent in both species.

Action: Calculate final concentrations.

After: $[\text{N}_2\text{O}_4] = 0.495025$; $[\text{NO}_2] = 0.00995012$

Why: Keep guard digits while checking the solution.

Step 23

Before: Proposed final concentrations are now known.

Action: Check the quotient and conserved atoms.

After: $Q = 0.00995012^2/0.495025 \approx 0.0002$; $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1$

Why: Both the equilibrium ratio and starting atom inventory agree.

Estimated depletion 1.00%; passes this stated screen.

Follow the model

An equilibrium mixture has both concentrations 0.200. Halve its volume at unchanged temperature. Find the new equilibrium.

Step 1

Before: Amount is unchanged during rapid compression.

Action: Divide volume by two.

After: Both concentrations immediately become 0.400

Why: Concentration equals amount divided by volume.

Step 2

Before: $Q = 0.400^2/0.400$

Action: Calculate and compare.

After: $Q = 0.400 > K = 0.200$

Why: K remains unchanged because temperature is unchanged.

Step 3

Before: Net change is reverse.

Action: Use +x and -2x.

After: $[N_2O_4] = 0.400 + x$; $[NO_2] = 0.400 - 2x$

Why: $0 \leq x \leq 0.200$.

Step 4

Before: $0.200 = (0.400 - 2x)^2/(0.400 + x)$

Action: Multiply by the denominator and expand.

After: $0.160 - 1.600x + 4x^2 = 0.0800 + 0.200x$

Why: The middle term of the square remains essential.

Step 5

Before: $0.160 - 1.600x + 4x^2 = 0.0800 + 0.200x$

Action: Subtract the right expression from both sides.

After: $4x^2 - 1.800x + 0.0800 = 0$

Why: Both sides undergo the same operations.

Step 6

Before: $a = 4$; $b = -1.800$; $c = 0.0800$

Action: Use the quadratic formula.

After: $x = (1.800 \pm \sqrt{(3.240 - 1.280)})/8 = 0.0500$ or 0.400

Why: The second root exceeds 0.200 and gives negative NO_2 .

Step 7

Before: Valid $x = 0.0500$

Action: Substitute and check.

After: $[\text{N}_2\text{O}_4] = 0.450$; $[\text{NO}_2] = 0.300$; $Q = 0.300^2/0.450 = 0.200$

Why: The new NO_2 concentration exceeds its original 0.200 even though reaction adjusted leftwards.

New equilibrium: $0.450 \text{ mol L}^{-1} \text{ N}_2\text{O}_4$ and $0.300 \text{ mol L}^{-1} \text{ NO}_2$.

Follow the model

At fixed volume, heat an equilibrium mixture with both concentrations 0.200. Supplied K changes from 0.200 to 0.600. Find the new equilibrium.

Step 1

Before: The volume and amounts have not yet changed.

Action: Compare current Q with the new K.

After: $Q = 0.200 < \text{new } K = 0.600$

Why: Temperature changed K; reaction then changes concentrations.

Step 2

Before: Net change is forward.

Action: Use $-x$ and $+2x$.

After: $[\text{N}_2\text{O}_4] = 0.200 - x$; $[\text{NO}_2] = 0.200 + 2x$

Why: $0 \leq x \leq 0.200$.

Step 3

Before: $0.600 = (0.200 + 2x)^2 / (0.200 - x)$

Action: Multiply by the denominator and expand.

After: $0.120 - 0.600x = 0.0400 + 0.800x + 4x^2$

Why: The square has three terms.

Step 4

Before: $0.120 - 0.600x = 0.0400 + 0.800x + 4x^2$

Action: Add $0.600x$ and subtract 0.120 on both sides.

After: $4x^2 + 1.400x - 0.0800 = 0$

Why: Equal operations collect the quadratic.

Step 5

Before: $a = 4$; $b = 1.400$; $c = -0.0800$

Action: Calculate both roots.

After: $x = (-1.400 \pm \sqrt{(1.960 + 1.280)})/8 = 0.0500$ or -0.400

Why: Reject the negative forward extent.

Step 6

Before: $x = 0.0500$

Action: Substitute and check.

After: $[\text{N}_2\text{O}_4] = 0.150$; $[\text{NO}_2] = 0.300$; $Q = 0.300^2/0.150 = 0.600$

Why: The new concentrations satisfy the new equilibrium constant.

New equilibrium: $0.150 \text{ mol L}^{-1} \text{ N}_2\text{O}_4$ and $0.300 \text{ mol L}^{-1} \text{ NO}_2$.

Follow the model

$K = 0.200$ for $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$. Find the constant for $2\text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4$.

Step 1

Before: Original $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Write the expression for the reversed equation.

After: Reverse constant = $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2$

Why: The new reactant and product roles swap; their balanced exponents stay attached to each formula.

Step 2

Before: $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2$

Action: Recognise the reciprocal of the original ratio.

After: Reverse constant = $1/K$

Why: Multiplying the two ratios cancels matching concentration factors and gives one.

Step 3

Before: Reverse constant = $1/K$

Action: Substitute and calculate.

After: $1/0.200 = 5.00$

Why: Check: $5.00 \times 0.200 = 1.00$.

The reversed constant is 5.00.

Follow the model

$K = 0.200$ for $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$. Find the constant for $2\text{N}_2\text{O}_4 \rightleftharpoons 4\text{NO}_2$.

Step 1

Before: Balanced coefficients are now two and four.

Action: Apply each coefficient as an exponent.

After: New constant = $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2$

Why: A coefficient changes an exponent, not a multiplier outside the expression.

Step 2

Before: $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2$

Action: Rewrite as the square of the original ratio.

After: $([\text{NO}_2]^2/[\text{N}_2\text{O}_4])^2 = K^2$

Why: Squaring a quotient squares its numerator and denominator.

Step 3

Before: New constant = K^2

Action: Substitute and square the full numerical constant.

After: $0.200^2 = 0.0400$

Why: Using the equilibrium pair 0.200 and 0.200: $0.200^4/0.200^2 = 0.0400$, confirming the new expression.

The doubled-equation constant is 0.0400.

Together — We do

Follow the guided example

Complete the forward ICE equation after expansion from concentrations 0.225 N₂O₄ and 0.150 NO₂. Supplied K = 0.200 at this fixed temperature.

Step 1

Before: $Q = 0.150^2/0.225 = 0.100 < K$

Action: Complete the change signs.

After: N₂O₄: -x; NO₂: +2x

Why: Forward change consumes reactant.

Step 2

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Complete the equilibrium substitution.

After: $0.200 = (0.150 + 2x)^2/(0.225 - x)$

Why: The product expression is squared as a whole.

Expand and collect $4x^2 + 0.800x - 0.0225 = 0$. Valid $x = 0.0250$. Final concentrations both 0.200.

Question 1

Complete the counts for 3N₂O₄ and 6NO₂. Do they contain matching totals?

Answer and working

3N₂O₄: N = 3 × 2 = 6; O = 3 × 4 = 12.

6NO₂: N = 6 × 1 = 6; O = 6 × 2 = 12.

Atom totals match, although molecule counts differ.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use the coefficient to multiply each subscript.

For 3N₂O₄, nitrogen count is three groups of two.

Find both oxygen totals, then compare each element separately.

Question 2

Rearrange $0.100 - 0.200x = 4x^2$ into a quadratic equal to zero. Show the operation on both sides.

Answer and working

Add $0.200x$ to both sides: $0.100 - 0.200x + 0.200x = 4x^2 + 0.200x$, so $0.100 = 4x^2 + 0.200x$.

Subtract 0.100 from both sides: $0 = 4x^2 + 0.200x - 0.100$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Preserve equality while collecting the quadratic terms.

Add $0.200x$ to both sides; the opposite x terms sum to zero.

Now subtract 0.100 from both sides and write the quadratic expression on the left.

Question 5



Keep coefficients in Q and ICE

Separate immediate and later states

Track the supplied mixture

$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ Keep coefficients in Q and ICE Separate immediate and later states

Complete $Q = \frac{\text{products}}{\text{reactants}}$ for $[\text{NO}_2] = 0.300$ and $[\text{N}_2\text{O}_4] = 0.450$. Decide whether the mixture is at equilibrium. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.3$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.3^2 = 0.09$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.09; reactant 0.45

Action: Divide the product square by reactant concentration.

After: $Q = 0.09/0.45 = 0.2$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.2$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is equal to K: dynamic equilibrium.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

$Q = 0.300^2/0.450 = 0.0900/0.450 = 0.200 = K$. The mixture is at dynamic equilibrium.

$Q = 0.300^2/0.450 = 0.0900/0.450 = 0.200 = K$.

The mixture is at dynamic equilibrium.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use the balanced coefficient as the exponent.

Square 0.300 before dividing by 0.450.

The quotient equals the supplied reference; explain what this means for net change.

Question 6

Keep coefficients in Q and ICE

Separate immediate and later states

Track the supplied mixture

$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ Keep coefficients in Q and ICE Separate immediate and later states

A mixture starts with $[\text{N}_2\text{O}_4] = 0.450$ and $[\text{NO}_2] = 0.300$, then volume doubles at fixed temperature. Complete immediate concentrations and the ICE change signs. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Immediate concentrations are 0.225 and 0.150.

$$Q = 0.150^2/0.225 = 0.100 < K.$$

Net change is forward, so changes are $-x$ for N_2O_4 and $+2x$ for NO_2 .

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Separate immediate dilution from reaction adjustment.

Doubling volume halves both concentrations.

Calculate Q from the halved values and use its comparison to K for the signs.

Question 7

Keep coefficients in Q and ICE

Separate immediate and later states

Track the supplied mixture

$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ Keep coefficients in Q and ICE Separate immediate and later states

After that expansion, complete $(0.150 + 2x)^2 = 0.200(0.225 - x)$, then find the physical root.

Answer and working**Step 1**

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.15$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.15^2 = 0.0225$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.0225; reactant 0.225

Action: Divide the product square by reactant concentration.

After: $Q = 0.0225/0.225 = 0.1$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.1$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is below K : net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K .

Step 5

Before: The quotient determines the net reaction direction.

Action: Define nonnegative x as N_2O_4 consumed.

After: $[\text{N}_2\text{O}_4] = 0.225 - x$; $[\text{NO}_2] = 0.15 + 2x$

Why: The balanced equation gives one-to-two concentration changes.

Step 6

Before: Every final concentration must be nonnegative.

Action: Set the extent bounds.

After: $0 \leq x \leq 0.225$

Why: Reject roots that violate these bounds or give zero denominator at finite K .

Step 7

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute both equilibrium expressions.

After: $0.2 = (0.15 + 2x)^2/(0.225 - x)$

Why: Square the entire numerator bracket.

Step 8

Before: $0.2 = (0.15 + 2x)^2/(0.225 - x)$

Action: Multiply both sides by $0.225 - x$.

After: $0.2(0.225 - x) = (0.15 + 2x)^2$

Why: The denominator factor reduces to one.

Step 9

Before: $(0.15 + 2x)^2$

Action: Expand the square, including its middle term.

After: $0.0225 + 0.6x + 4x^2$

Why: Use $u^2 \pm 2uv + v^2$; here v is $2x$.

Step 10

Before: $0.2(0.225 - x)$

Action: Distribute K to both terms.

After: $0.045 - 0.2x$

Why: Both the constant term and the x term are multiplied by K.

Step 11

Before: $0.0225 + 0.6x + 4x^2 = 0.045 - 0.2x$

Action: Subtract 0.045 from both sides.

After: $-0.0225 + 0.6x + 4x^2 = -0.2x$

Why: The matching constant on the right sums to zero.

Step 12

Before: The right side contains $-0.2x$.

Action: Add $0.2x$ on both sides.

After: $4x^2 + 0.8x - 0.0225 = 0$

Why: Combine the x coefficients; the opposite right-side x terms sum to zero.

Step 13

Before: $4x^2 + 0.8x - 0.0225 = 0$

Action: Read the quadratic coefficients.

After: $a = 4$; $b = 0.8$; $c = -0.0225$

Why: Retain each coefficient sign.

Step 14

Before: Discriminant $= b^2 - 4ac$

Action: Substitute and calculate.

After: $(0.8)^2 - 4 \times 4 \times (-0.0225) = 1$

Why: Bracket a negative coefficient when substituting.

Step 15

Before: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Action: Substitute into the quadratic formula.

After: $x = \frac{-(0.8) \pm \sqrt{1}}{8}$

Why: Calculate both signs; the denominator is two times four.

Step 16

Before: Both signs of the formula are required.

Action: Calculate both numerical roots.

After: $x = 0.025$ or -0.225

Why: Use the physical constraints to choose the valid root.

Step 17

Before: $0 \leq x \leq 0.225$

Action: Reject $x = -0.225$.

After: Use $x = 0.025$

Why: The rejected value violates the extent bounds and gives a negative species concentration.

Step 18

Before: Use the valid extent in both species.

Action: Calculate final concentrations.

After: $[\text{N}_2\text{O}_4] = 0.2$; $[\text{NO}_2] = 0.2$

Why: Keep guard digits while checking the solution.

Step 19

Before: Proposed final concentrations are now known.

Action: Check the quotient and conserved atoms.

After: $Q = 0.2^2/0.2 \approx 0.2$; $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 0.6$

Why: Both the equilibrium ratio and starting atom inventory agree.

Expand: $0.0225 + 0.600x + 4x^2 = 0.0450 - 0.200x$. Add $0.200x$ and subtract 0.0450 on both sides: $4x^2 + 0.800x - 0.0225 = 0$. Roots: $(-0.800 \pm \sqrt{(0.640 + 0.360)})/8 = 0.0250$ or -0.225 . Reject the negative forward extent.

Expand: $0.0225 + 0.600x + 4x^2 = 0.0450 - 0.200x$.

Add $0.200x$ and subtract 0.0450 on both sides: $4x^2 + 0.800x - 0.0225 = 0$.

Roots: $(-0.800 \pm \sqrt{(0.640 + 0.360)})/8 = 0.0250$ or -0.225 .

Reject the negative forward extent.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Expand the square with its middle term.

The expanded equality is $0.0225 + 0.600x + 4x^2 = 0.0450 - 0.200x$.

Collect $4x^2 + 0.800x - 0.0225 = 0$. Use both signs, then test $0 \leq x \leq 0.225$.

Question 20

At fixed volume, both concentrations remain 0.200 immediately after heating changes K from 0.200 to 0.600. Complete current Q and the net direction.

Answer and working

$Q = 0.200^2/0.200 = 0.200$.

Compare with the new $K = 0.600$: $Q < K$.

Net forward change forms more NO_2 and consumes N_2O_4 .

Temperature changed K; amounts have not yet adjusted.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Separate a changed equilibrium reference from unchanged immediate concentrations.

Calculate Q from both current concentrations 0.200.

Compare your quotient with the new constant 0.600, then select the net direction.

Question 21

At a different supplied temperature the original reaction has $K = 0.500$. Complete the reverse constant $1/\underline{\hspace{1cm}}$ and doubled-equation constant $(\underline{\hspace{1cm}})^2$.

Answer and working

Reverse: $1/0.500 = 2.00$.

Doubled equation: $0.500^2 = 0.250$.

Reversal swaps numerator and denominator; doubled coefficients square the full original expression.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Rewrite each balanced equation and its expression.

Reversing gives the reciprocal $1/K$; doubling coefficients doubles exponents.

Use the supplied 0.500 in each expression; calculate the reciprocal and square separately.

Question 22

A proposed shortcut gives estimated extent 0.00300 from initial reactant 0.300. Complete the depletion calculation $\frac{\text{---}}{\text{---}} \times 100\%$. Does it pass a stated 5% screen, and does that alone establish numerical accuracy?

Answer and working

Depletion estimate = $0.00300/0.300 \times 100\% = 1.00\%$.

It passes the stated depletion screen.

This is only a consistency screen for the small-x assumption; the full equation or required numerical precision must still justify the final accuracy.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use the estimated extent as a fraction of initial reactant.

Write $0.00300/0.300 \times 100\%$.

Calculate the percentage and compare with five; distinguish this screen from an exact-equation check.

With help

Apply the method: teaching example

A prepared mixture has N_2O_4 0.400 and NO_2 0.200. Supplied $K = 0.200$ at this fixed temperature. Choose a method to predict its change.

Step 1

Before: Current concentrations and fixed-temperature K are given.

Action: Choose Q comparison; a full ICE solution is not necessary for direction alone.

After: $Q = 0.200^2/0.400 = 0.100 < K$

Why: Net forward change occurs; N_2O_4 decreases and NO_2 increases.

Net forward change. Use a full ICE equation only if final concentrations are required.

Question 3

N_2O_4 change: -0.0200

NO_2 change: twice the opposite amount

Check nitrogen and oxygen separately

One extent changes both species

N_2O_4 change: -0.0200 NO_2 change: twice the opposite amount Check nitrogen and oxygen separately

An extent of $0.0200 \text{ mol L}^{-1}$ N_2O_4 is consumed at fixed volume. State both concentration changes and check atom conservation.

Answer and working

$\Delta[\text{N}_2\text{O}_4] = -0.0200 \text{ mol L}^{-1}$; $\Delta[\text{NO}_2] = +0.0400 \text{ mol L}^{-1}$.

Nitrogen change: $2 \times (-0.0200) + 0.0400 = 0$; oxygen change is twice that, also zero.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use the balanced one-to-two relationship.

Set the N_2O_4 change to minus the stated extent.

NO_2 forms at twice that extent. Check two times the reactant change plus the product change.

Question 4

Expand $(0.400 - 2x)^2$ and collect terms in $(0.400 - 2x)^2 = 0.200(0.100 + x)$.

Answer and working

$$(u - v)^2 = u^2 - 2uv + v^2.$$

Here the left becomes $0.160 - 1.600x + 4x^2$; the right is $0.0200 + 0.200x$.

Subtract the right expression from both sides: $4x^2 - 1.800x + 0.140 = 0$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use the square of a difference, including its middle term.

Expand both sides: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$.

Subtract the entire right expression from both sides, then combine like terms.

Question 8

For reverse change from $[N_2O_4] = 0.100$ and $[NO_2] = 0.400$, decide whether $x = 0.350$ is physical.

Answer and working

$$[NO_2] = 0.400 - 2 \times 0.350 = -0.300.$$

A negative concentration is impossible; reject the root.

The allowed reverse extent is at most 0.200.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use concentration bounds to test the proposed extent.

Substitute into $[NO_2] = 0.400 - 2x$.

The proposed product concentration is below zero; explain the physical consequence.

Question 9

A learner estimates $x = 0.158$ from initial $[\text{N}_2\text{O}_4] = 0.500$. Assess the approximation using a stated 5% depletion screen.

Answer and working

Depletion estimate = $0.158/0.500 \times 100\% = 31.6\%$.

This exceeds the chosen 5% screen.

Use the full quadratic.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Test the assumption after estimating x .

Divide the estimated extent by the initial reactant concentration.

Convert the fraction to per cent and compare with the stated tolerance.

Question 10

At fixed temperature, both equilibrium concentrations 0.200 are doubled by compression. Predict adjustment and state whether K changes.

Answer and working

$Q = 0.400^2/0.400 = 0.400 > K$.

Net change is leftwards.

Temperature is unchanged, so K stays 0.200.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Calculate Q at the immediate compressed state.

Both concentrations become 0.400 before reaction adjustment.

Compare the quotient with the unchanged temperature-dependent reference.

On my own

Question 11

Initially $[\text{N}_2\text{O}_4] = 0.400$ and $[\text{NO}_2] = 0.200$. Predict direction and explain. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.2$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.2^2 = 0.04$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.04; reactant 0.4

Action: Divide the product square by reactant concentration.

After: $Q = 0.04/0.4 = 0.1$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.1$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is below K: net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

$Q = 0.200^2/0.400 = 0.100 < 0.200$. Net change is forward; N_2O_4 decreases and NO_2 increases.

$Q = 0.200^2/0.400 = 0.100 < 0.200$.

Net change is forward; N_2O_4 decreases and NO_2 increases.

What to look for

- Uses the stated physical or chemical relationship.

- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K, the physical bounds and the stated constraint.

Question 12

An equilibrium mixture has $[\text{N}_2\text{O}_4] = 0.450$ and $[\text{NO}_2] = 0.300$. Prove that it satisfies $K = 0.200$.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.3$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.3^2 = 0.09$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.09; reactant 0.45

Action: Divide the product square by reactant concentration.

After: $Q = 0.09/0.45 = 0.2$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.2$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is equal to K: dynamic equilibrium.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

$Q = 0.300^2/0.450 = 0.0900/0.450 = 0.200$. It satisfies the equilibrium condition at this temperature.

$$Q = 0.300^2/0.450 = 0.0900/0.450 = 0.200.$$

It satisfies the equilibrium condition at this temperature.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K, the physical bounds and the stated constraint.

Question 13

Initially $[\text{N}_2\text{O}_4] = 0.100$ and $[\text{NO}_2] = 0.400$. Construct and solve the reverse ICE equation, rejecting invalid roots. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: $Q = 0.400^2/0.100 = 1.60$.

Action: Compare with K .

After: $Q > 0.200$; net reverse change.

Why: Define x as N_2O_4 formed.

Step 2

Before: One N_2O_4 forms from two NO_2 .

Action: Write reverse changes.

After: $[\text{N}_2\text{O}_4] = 0.100 + x$; $[\text{NO}_2] = 0.400 - 2x$

Why: The range is $0 \leq x \leq 0.200$.

Step 3

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute and multiply both sides by $0.100 + x$.

After: $(0.400 - 2x)^2 = 0.200(0.100 + x)$

Why: The whole squared bracket must be expanded.

Step 4

Before: $(u - v)^2 = u^2 - 2uv + v^2$

Action: Expand both sides.

After: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$

Why: The middle term includes twice 0.400 times 2x.

$$\begin{aligned}(0.400 - 2x)^2 \\&= 0.400^2 - 2 \times 0.400 \times 2x + (2x)^2 \\&= 0.160 - 1.600x + 4x^2\end{aligned}$$

Expand all three square terms

$$(0.400 - 2x)^2 = 0.400^2 - 2 \times 0.400 \times 2x + (2x)^2 = 0.160 - 1.600x + 4x^2$$

Step 5

Before: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$

Action: Subtract 0.0200 and 0.200x from both sides.

After: $4x^2 - 1.800x + 0.140 = 0$

Why: Equal operations preserve the equation.

Step 6

Before: $a = 4$; $b = -1.800$; $c = 0.140$

Action: Use both signs of the quadratic formula.

After: $x = (1.800 \pm \sqrt{(3.240 - 2.240)})/8$; $x = 0.100$ or 0.350

Why: The discriminant is 1.000.

Step 7

Before: x must be at most 0.200.

Action: Reject $x = 0.350$.

After: $x = 0.100$

Why: The other root gives $[\text{NO}_2] = 0.400 - 0.700 = -0.300$, impossible.

Step 8

Before: $x = 0.100$

Action: Calculate and check both concentrations.

After: $[\text{N}_2\text{O}_4] = 0.200$; $[\text{NO}_2] = 0.200$; $Q = 0.200$

Why: $2 \times 0.200 + 0.200 = 0.600$, matching $2 \times 0.100 + 0.400$.

$Q = 1.60 > K$. Let x be N_2O_4 formed. $(0.400 - 2x)^2 = 0.200(0.100 + x)$. Expand and collect: $4x^2 - 1.800x + 0.140 = 0$. Roots $x = 0.100$ and 0.350 ; reject the latter because it gives negative NO_2 . Final concentrations both 0.200 . Check $Q = 0.200$.

$Q = 1.60 > K$.

Let x be N_2O_4 formed.

$$(0.400 - 2x)^2 = 0.200(0.100 + x).$$

Expand and collect: $4x^2 - 1.800x + 0.140 = 0$.

Roots $x = 0.100$ and 0.350 ; reject the latter because it gives negative NO_2 .

Final concentrations both 0.200 .

Check $Q = 0.200$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K , the physical bounds and the stated constraint.

Question 14

A rapid expansion halves concentrations initially 0.450 N₂O₄ and 0.300 NO₂. Find the new equilibrium at K = 0.200.

Answer and working

Step 1

Before: N₂O₄(g) ⇌ 2NO₂(g)

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2 / [\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: [NO₂] = 0.15

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.15^2 = 0.0225$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.0225; reactant 0.225

Action: Divide the product square by reactant concentration.

After: $Q = 0.0225 / 0.225 = 0.1$

Why: Use the current values to calculate Q.

Step 4

Before: Q = 0.1; K = 0.2

Action: Compare Q with the reference at this temperature.

After: Q is below K: net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

Step 5

Before: The quotient determines the net reaction direction.

Action: Define nonnegative x as N₂O₄ consumed.

After: $[\text{N}_2\text{O}_4] = 0.225 - x$; $[\text{NO}_2] = 0.15 + 2x$

Why: The balanced equation gives one-to-two concentration changes.

Step 6

Before: Every final concentration must be nonnegative.

Action: Set the extent bounds.

After: $0 \leq x \leq 0.225$

Why: Reject roots that violate these bounds or give zero denominator at finite K.

Step 7

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute both equilibrium expressions.

After: $0.2 = (0.15 + 2x)^2/(0.225 - x)$

Why: Square the entire numerator bracket.

Step 8

Before: $0.2 = (0.15 + 2x)^2/(0.225 - x)$

Action: Multiply both sides by $0.225 - x$.

After: $0.2(0.225 - x) = (0.15 + 2x)^2$

Why: The denominator factor reduces to one.

Step 9

Before: $(0.15 + 2x)^2$

Action: Expand the square, including its middle term.

After: $0.0225 + 0.6x + 4x^2$

Why: Use $u^2 \pm 2uv + v^2$; here v is $2x$.

Step 10

Before: $0.2(0.225 - x)$

Action: Distribute K to both terms.

After: $0.045 - 0.2x$

Why: Both the constant term and the x term are multiplied by K.

Step 11

Before: $0.0225 + 0.6x + 4x^2 = 0.045 - 0.2x$

Action: Subtract 0.045 from both sides.

After: $-0.0225 + 0.6x + 4x^2 = -0.2x$

Why: The matching constant on the right sums to zero.

Step 12

Before: The right side contains $-0.2x$.

Action: Add $0.2x$ on both sides.

After: $4x^2 + 0.8x - 0.0225 = 0$

Why: Combine the x coefficients; the opposite right-side x terms sum to zero.

Step 13

Before: $4x^2 + 0.8x - 0.0225 = 0$

Action: Read the quadratic coefficients.

After: $a = 4$; $b = 0.8$; $c = -0.0225$

Why: Retain each coefficient sign.

Step 14

Before: Discriminant = $b^2 - 4ac$

Action: Substitute and calculate.

After: $(0.8)^2 - 4 \times 4 \times (-0.0225) = 1$

Why: Bracket a negative coefficient when substituting.

Step 15

Before: $x = (-b \pm \sqrt{b^2 - 4ac})/(2a)$

Action: Substitute into the quadratic formula.

After: $x = (-(0.8) \pm \sqrt{1})/8$

Why: Calculate both signs; the denominator is two times four.

Step 16

Before: Both signs of the formula are required.

Action: Calculate both numerical roots.

After: $x = 0.025$ or -0.225

Why: Use the physical constraints to choose the valid root.

Step 17

Before: $0 \leq x \leq 0.225$

Action: Reject $x = -0.225$.

After: Use $x = 0.025$

Why: The rejected value violates the extent bounds and gives a negative species concentration.

Step 18

Before: Use the valid extent in both species.

Action: Calculate final concentrations.

After: $[\text{N}_2\text{O}_4] = 0.2$; $[\text{NO}_2] = 0.2$

Why: Keep guard digits while checking the solution.

Step 19

Before: Proposed final concentrations are now known.

Action: Check the quotient and conserved atoms.

After: $Q = 0.2^2/0.2 \approx 0.2$; $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 0.6$

Why: Both the equilibrium ratio and starting atom inventory agree.

Immediate values 0.225 and 0.150 give $Q = 0.100 < K$. $(0.150 + 2x)^2 = 0.200(0.225 - x)$. Expand and collect $4x^2 + 0.800x - 0.0225 = 0$. Roots 0.0250 and -0.225 ; reject negative forward extent. Final concentrations: $\text{N}_2\text{O}_4 = 0.200$, $\text{NO}_2 = 0.200$. Check $Q = 0.200$.

Immediate values 0.225 and 0.150 give $Q = 0.100 < K$.

$(0.150 + 2x)^2 = 0.200(0.225 - x)$.

Expand and collect $4x^2 + 0.800x - 0.0225 = 0$.

Roots 0.0250 and -0.225 ; reject negative forward extent.

Final concentrations: $\text{N}_2\text{O}_4 = 0.200$, $\text{NO}_2 = 0.200$.

Check $Q = 0.200$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K , the physical bounds and the stated constraint.

Question 15

A suitable catalyst is added to an equilibrium mixture at unchanged temperature. Does equilibrium NO_2 concentration rise? Explain.

Answer and working

No.

A catalyst increases both reaction rates without changing K or equilibrium composition.

At equilibrium rates remain equal; no net composition change occurs.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K , the physical bounds and the stated constraint.

Question 16

At fixed volume, heating changes K from 0.200 to 0.600 while both concentrations initially remain 0.200. Predict the net change and explain why this differs from compression.

Answer and working

Initial Q remains 0.200 but is below new $K = 0.600$, so net forward change occurs.

Heating changed K ; compression at fixed temperature changes Q while K stays unchanged.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K , the physical bounds and the stated constraint.

Question 17

A proposed final pair 0.200 N₂O₄ and 0.200 NO₂ satisfies K. Could it come from initial 0.500 N₂O₄ and zero NO₂ in a closed fixed-volume vessel?

Answer and working

No.

Initial atom inventory $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1.000$.

Proposed pair gives $2 \times 0.200 + 0.200 = 0.600$.

It satisfies K but fails atom conservation.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K, the physical bounds and the stated constraint.

Question 18

With original $K = 0.200$, find constants for the reversed and doubled balanced equations. Explain using exponents.

Answer and working

Step 1

Before: Original $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Write the expression for the reversed equation.

After: Reverse constant = $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2$

Why: The new reactant and product roles swap; their balanced exponents stay attached to each formula.

Step 2

Before: $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2$

Action: Recognise the reciprocal of the original ratio.

After: Reverse constant = $1/K$

Why: Multiplying the two ratios cancels matching concentration factors and gives one.

Step 3

Before: Reverse constant = $1/K$

Action: Substitute and calculate.

After: $1/0.200 = 5.00$

Why: Check: $5.00 \times 0.200 = 1.00$.

Step 4

Before: Balanced coefficients are now two and four.

Action: Apply each coefficient as an exponent.

After: New constant = $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2$

Why: A coefficient changes an exponent, not a multiplier outside the expression.

Step 5

Before: $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2$

Action: Rewrite as the square of the original ratio.

After: $([\text{NO}_2]^2/[\text{N}_2\text{O}_4])^2 = K^2$

Why: Squaring a quotient squares its numerator and denominator.

Step 6

Before: New constant = K^2

Action: Substitute and square the full numerical constant.

After: $0.200^2 = 0.0400$

Why: Using the equilibrium pair 0.200 and 0.200: $0.200^4/0.200^2 = 0.0400$, confirming the new expression.

Reverse: $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2 = 1/K = 5.00$. Doubled: $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2 = K^2 = 0.0400$. Doubling coefficients doubles exponents, so it squares rather than doubles K.

Reverse: $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2 = 1/K = 5.00$.

Doubled: $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2 = K^2 = 0.0400$.

Doubling coefficients doubles exponents, so it squares rather than doubles K.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify the requested comparison, calculation or claim.

Write the balanced equation and the quotient or conservation relationship relevant to the stated conditions.

Carry the coefficient two through the working; check the result against K, the physical bounds and the stated constraint.

Question 19

Which statement is justified at fixed temperature?

Circle your answer:

- A. Compression changes Q immediately; K remains unchanged.
- B. Compression doubles K .
- C. A catalyst increases equilibrium product concentration.

Answer and working

K depends on temperature for the stated reaction convention.

Compression changes concentrations and Q ; a catalyst changes rates.

Hints to offer

Identify the relationship being tested.

Use the definitions before comparing the options.

Reject options that contradict the relationship; select the remaining option.

Question 23

A shortcut that neglects x gives estimated extent 0.0200 from initial reactant 0.200. Assess it using a stated 5% depletion screen and specify the next calculation.

Answer and working

Depletion estimate = $0.0200/0.200 \times 100\% = 10.0\%$.

It fails the stated 5% screen.

Restore the extent in the denominator, solve the full ICE equation, test both quadratic roots and check the quotient.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Test the neglected term relative to the initial amount.

Use extent divided by initial reactant, then multiply by 100%.

Compare the computed percentage with the stated screen; identify which term must be restored.

Come back

Question 24

Sketch one N_2O_4 forming two NO_2 . Count atoms and explain why changing product subscripts is invalid.

Answer and working

Step 1

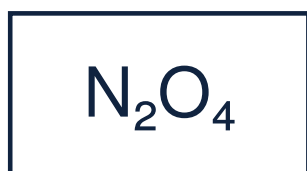
Before: One N_2O_4 molecule.

Action: Count subscripts.

After: Two nitrogen atoms and four oxygen atoms.

Why: A subscript gives atom count in one molecule.

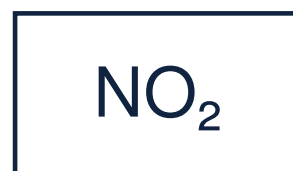
One molecule



Two molecules



+



N: 2 O: 4

N: 1 + 1 O: 2 + 2

Atom totals match; molecule counts differ.

Coefficients conserve atoms

One dinitrogen tetroxide composition token corresponds to two nitrogen dioxide tokens. Each side has two nitrogen atoms and four oxygen atoms. Molecule counts differ. Tokens show composition, not molecular geometry.

Step 2

Before: One NO_2 contains one nitrogen and two oxygen atoms.

Action: Use two NO_2 molecules.

After: Nitrogen: $2 \times 1 = 2$. Oxygen: $2 \times 2 = 4$.

Why: The coefficient multiplies every atom count in the formula; formulas remain unchanged.

N_2O_4 has two N and four O atoms. Two NO_2 have $2 \times 1 = 2$ N and $2 \times 2 = 4$ O. Atom totals match. Changing a subscript changes the substance; coefficient changes preserve the formula.

N_2O_4 has two N and four O atoms.

Two NO_2 have $2 \times 1 = 2$ N and $2 \times 2 = 4$ O.

Atom totals match.

Changing a subscript changes the substance; coefficient changes preserve the formula.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 25

At equilibrium $[\text{NO}_2] = 0.200$ and $[\text{N}_2\text{O}_4] = 0.200$. Calculate K and justify the exponent.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.2$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.2^2 = 0.04$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.04; reactant 0.2

Action: Divide the product square by reactant concentration.

After: $Q = 0.04/0.2 = 0.2$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.2$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is equal to K : dynamic equilibrium.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K .

$K = 0.200^2/0.200 = 0.0400/0.200 = 0.200$. The NO_2 coefficient two becomes exponent two, not a multiplier outside the square.

$K = 0.200^2/0.200 = 0.0400/0.200 = 0.200$.

The NO_2 coefficient two becomes exponent two, not a multiplier outside the square.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K .

Question 26

A prepared mixture has $[\text{NO}_2] = 0.200$ and $[\text{N}_2\text{O}_4] = 0.300$. Predict its net reaction direction. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: Current concentrations may not be equilibrium values.

Action: Use Q to describe the present state.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: K is the equilibrium reference at this temperature.

Step 2

Before: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Square product concentration, then divide.

After: $Q = (0.200)^2/0.300 = 0.133$

Why: The coefficient two becomes an exponent.

Step 3

Before: $Q = 0.133$; $K = 0.200$

Action: Compare the two values.

After: Net change is rightwards.

Why: Q below K needs a larger ratio; Q above K needs a smaller ratio.

$Q = 0.200^2/0.300 = 0.133 < 0.200$. Net forward change consumes N_2O_4 and forms NO_2 until Q reaches K .

$Q = 0.200^2/0.300 = 0.133 < 0.200$.

Net forward change consumes N_2O_4 and forms NO_2 until Q reaches K .

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K .

Question 27

A prepared mixture has $[\text{NO}_2] = 0.400$ and $[\text{N}_2\text{O}_4] = 0.200$. Predict changes and express them using a nonnegative extent x . Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: Current concentrations may not be equilibrium values.

Action: Use Q to describe the present state.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: K is the equilibrium reference at this temperature.

Step 2

Before: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Square product concentration, then divide.

After: $Q = (0.400)^2/0.200 = 0.800$

Why: The coefficient two becomes an exponent.

Step 3

Before: $Q = 0.800$; $K = 0.200$

Action: Compare the two values.

After: Net change is leftwards.

Why: Q below K needs a larger ratio; Q above K needs a smaller ratio.

$Q = 0.400^2/0.200 = 0.800 > K$. Net reverse change: $\Delta[\text{N}_2\text{O}_4] = +x$ and $\Delta[\text{NO}_2] = -2x$.

$Q = 0.400^2/0.200 = 0.800 > K$.

Net reverse change: $\Delta[\text{N}_2\text{O}_4] = +x$ and $\Delta[\text{NO}_2] = -2x$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K .

Question 28

A learner says the reaction stops when both concentrations are 0.200 because Q equals K. Evaluate.

Answer and working

$$Q = 0.200^2/0.200 = 0.200 = K.$$

Equilibrium is dynamic: forward and reverse reactions continue at equal rates.

Concentrations have no net change.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 29

Initially $[\text{N}_2\text{O}_4] = 0.500$ and $[\text{NO}_2] = 0$. Find equilibrium concentrations using the complete quadratic and reject the invalid root. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: Initial $Q = 0^2/0.500 = 0$.

Action: Compare with $K = 0.200$.

After: $Q < K$, so net forward change.

Why: Reactant is consumed; product forms.

Step 2

Before: Define x as concentration of N_2O_4 consumed.

Action: Apply the balanced coefficients.

After: $[\text{N}_2\text{O}_4] = 0.500 - x$; $[\text{NO}_2] = 2x$

Why: One reactant unit gives two product units.

Initial: N_2O_4 0.500; NO_2 0

Change: N_2O_4 $-x$; NO_2 $+2x$

Equilibrium: $0.500 - x$; $2x$

Initial, change and equilibrium

Initial: N_2O_4 0.500; NO_2 0 Change: N_2O_4 $-x$; NO_2 $+2x$ Equilibrium: $0.500 - x$; $2x$

Step 3

Before: Concentrations cannot be negative.

Action: Set the physical range.

After: $0 \leq x \leq 0.500$

Why: The product concentration is $2x$ and reactant is $0.500 - x$.

Step 4

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute the equilibrium expressions.

After: $0.200 = (2x)^2/(0.500 - x)$

Why: Square the whole product expression, including coefficient two.

Step 5

Before: $0.200 = 4x^2/(0.500 - x)$

Action: Multiply both sides by $0.500 - x$.

After: $0.200(0.500 - x) = 4x^2$

Why: The denominator factor reduces to one; $x = 0.500$ cannot satisfy finite K.

$$0.200 = 4x^2/(0.500 - x)$$

$\times(0.500 - x)$ on both sides

$$0.200(0.500 - x) = 4x^2$$

Multiply both sides by the denominator

$$0.200 = 4x^2/(0.500 - x) \times (0.500 - x) \text{ on both sides } 0.200(0.500 - x) = 4x^2$$

Step 6

Before: $0.200(0.500 - x) = 4x^2$

Action: Distribute 0.200 across the bracket.

After: $0.100 - 0.200x = 4x^2$

Why: Multiply each term in the bracket.

Step 7

Before: $0.100 - 0.200x = 4x^2$

Action: Add $0.200x$ to both sides.

After: $0.100 = 4x^2 + 0.200x$

Why: The opposite x terms sum to zero.

$$\begin{array}{rcl} 0.100 - 0.200x & = & 4x^2 \\ +0.200x & & +0.200x \\ \hline 0.100 & \cancel{-0.200x} \quad \cancel{+0.200x} = & 4x^2 + 0.200x \end{array}$$

Opposite terms sum to zero.

$$0.100 = 4x^2 + 0.200x$$

Apply $+0.200x$ to both sides

$0.100 - 0.200x$ equals $4x^2$. Apply $+0.200x$ to each side. Result: 0.100 equals $4x^2 + 0.200x$. The marked opposite terms sum to zero.

Step 8

Before: $0.100 = 4x^2 + 0.200x$

Action: Subtract 0.100 from both sides.

After: $4x^2 + 0.200x - 0.100 = 0$

Why: Read the same equality with the quadratic on the left.

$$\begin{array}{rcl}
 0.100 & = & 4x^2 + 0.200x \\
 -0.100 & & -0.100 \\
 \hline
 \cancel{0.100} - \cancel{0.100} & = & 4x^2 + 0.200x - 0.100
 \end{array}$$

Opposite terms sum to zero.

$$0 = 4x^2 + 0.200x - 0.100$$

Apply -0.100 to both sides

0.100 equals $4x^2 + 0.200x$. Apply -0.100 to each side. Result: 0 equals $4x^2 + 0.200x - 0.100$. The marked opposite terms sum to zero.

Step 9

Before: $4x^2 + 0.200x - 0.100 = 0$

Action: Identify quadratic coefficients.

After: $a = 4$; $b = 0.200$; $c = -0.100$

Why: Include the negative sign in c .

Step 10

Before: $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Action: Substitute all coefficients.

After: $x = \frac{-0.200 \pm \sqrt{(0.0400 + 1.600)}}{8}$

Why: Subtracting the negative product adds 1.600.

Step 11

Before: Discriminant = 1.640.

Action: Calculate both signs.

After: $x = 0.135078$ or $x = -0.185078$

Why: Keep guard digits until final concentrations.

Step 12

Before: Physical range: $0 \leq x \leq 0.500$.

Action: Reject the negative root.

After: $x = 0.135078$

Why: A negative extent would produce negative NO_2 from an initial zero amount.

Step 13

Before: $[\text{N}_2\text{O}_4] = 0.500 - x$; $[\text{NO}_2] = 2x$

Action: Substitute the valid extent.

After: $[\text{N}_2\text{O}_4] = 0.364922$; $[\text{NO}_2] = 0.270156$

Why: Report approximately 0.365 and 0.270 mol L⁻¹ to three significant figures.

Step 14

Before: Proposed concentrations 0.364922 and 0.270156.

Action: Check quotient and atoms.

After: $0.270156^2/0.364922 \approx 0.200$; $2 \times 0.364922 + 0.270156 = 1.000$

Why: Both the equilibrium ratio and the initial nitrogen-atom inventory agree.

Let x be N_2O_4 consumed: concentrations $0.500 - x$ and $2x$. Multiply $K = 4x^2/(0.500 - x)$ by the denominator: $0.100 - 0.200x = 4x^2$. Add $0.200x$ and subtract 0.100 on both sides: $4x^2 + 0.200x - 0.100 = 0$. Roots $(-0.200 \pm \sqrt{1.640})/8 = 0.135078$ or -0.185078 . Reject negative x . Final $\text{N}_2\text{O}_4 = 0.364922$ and $\text{NO}_2 = 0.270156$. Their quotient is 0.200 and $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1.000$.

Let x be N_2O_4 consumed: concentrations $0.500 - x$ and $2x$.

Multiply $K = 4x^2/(0.500 - x)$ by the denominator: $0.100 - 0.200x = 4x^2$.

Add $0.200x$ and subtract 0.100 on both sides: $4x^2 + 0.200x - 0.100 = 0$.

Roots $(-0.200 \pm \sqrt{1.640})/8 = 0.135078$ or -0.185078 .

Reject negative x .

Final $\text{N}_2\text{O}_4 = 0.364922$ and $\text{NO}_2 = 0.270156$.

Their quotient is 0.200 and $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1.000$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use Q versus K to choose the direction before the ICE table.

Write equilibrium concentrations using one extent: reactant changes by x , product by twice x .

Multiply the quotient equation by its denominator on both sides, expand and collect the quadratic. Test both roots before reporting concentrations.

Question 30

Initially $[\text{N}_2\text{O}_4] = 0.100$ and $[\text{NO}_2] = 0.400$. Find equilibrium concentrations and reject the invalid root. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: $Q = 0.400^2/0.100 = 1.60$.

Action: Compare with K .

After: $Q > 0.200$; net reverse change.

Why: Define x as N_2O_4 formed.

Step 2

Before: One N_2O_4 forms from two NO_2 .

Action: Write reverse changes.

After: $[\text{N}_2\text{O}_4] = 0.100 + x$; $[\text{NO}_2] = 0.400 - 2x$

Why: The range is $0 \leq x \leq 0.200$.

Step 3

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute and multiply both sides by $0.100 + x$.

After: $(0.400 - 2x)^2 = 0.200(0.100 + x)$

Why: The whole squared bracket must be expanded.

Step 4

Before: $(u - v)^2 = u^2 - 2uv + v^2$

Action: Expand both sides.

After: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$

Why: The middle term includes twice 0.400 times 2x.

$$\begin{aligned}(0.400 - 2x)^2 \\&= 0.400^2 - 2 \times 0.400 \times 2x + (2x)^2 \\&= 0.160 - 1.600x + 4x^2\end{aligned}$$

Expand all three square terms

$$(0.400 - 2x)^2 = 0.400^2 - 2 \times 0.400 \times 2x + (2x)^2 = 0.160 - 1.600x + 4x^2$$

Step 5

Before: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$

Action: Subtract 0.0200 and 0.200x from both sides.

After: $4x^2 - 1.800x + 0.140 = 0$

Why: Equal operations preserve the equation.

Step 6

Before: $a = 4$; $b = -1.800$; $c = 0.140$

Action: Use both signs of the quadratic formula.

After: $x = (1.800 \pm \sqrt{(3.240 - 2.240)})/8$; $x = 0.100$ or 0.350

Why: The discriminant is 1.000.

Step 7

Before: x must be at most 0.200.

Action: Reject $x = 0.350$.

After: $x = 0.100$

Why: The other root gives $[\text{NO}_2] = 0.400 - 0.700 = -0.300$, impossible.

Step 8

Before: $x = 0.100$

Action: Calculate and check both concentrations.

After: $[\text{N}_2\text{O}_4] = 0.200$; $[\text{NO}_2] = 0.200$; $Q = 0.200$

Why: $2 \times 0.200 + 0.200 = 0.600$, matching $2 \times 0.100 + 0.400$.

$Q = 1.60 > K$. Let x be N_2O_4 formed. $(0.400 - 2x)^2 = 0.200(0.100 + x)$. Expand: $0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x$. Subtract the right expression on both sides: $4x^2 - 1.800x + 0.140 = 0$. Roots $(1.800 \pm 1.000)/8 = 0.100$ or 0.350 . Reject 0.350 , giving negative NO_2 . Final concentrations both 0.200 ; quotient 0.200 .

$Q = 1.60 > K$.

Let x be N_2O_4 formed.

$$(0.400 - 2x)^2 = 0.200(0.100 + x).$$

$$\text{Expand: } 0.160 - 1.600x + 4x^2 = 0.0200 + 0.200x.$$

$$\text{Subtract the right expression on both sides: } 4x^2 - 1.800x + 0.140 = 0.$$

$$\text{Roots } (1.800 \pm 1.000)/8 = 0.100 \text{ or } 0.350.$$

Reject 0.350 , giving negative NO_2 .

Final concentrations both 0.200 ; quotient 0.200 .

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use Q versus K to choose the direction before the ICE table.

Write equilibrium concentrations using one extent: reactant changes by x , product by twice x .

Multiply the quotient equation by its denominator on both sides, expand and collect the quadratic. Test both roots before reporting concentrations.

Question 31

For initial $[\text{N}_2\text{O}_4] = 0.500$ and zero NO_2 , test neglecting x when $K = 0.200$ using a stated 5% depletion screen.

Answer and working

Step 1

Before: $K = 4x^2/(0.500 - x)$

Action: Assume x is small relative to 0.500.

After: $K \approx 4x^2/0.500$

Why: This is a hypothesis to test, not an established equality.

Step 2

Before: $K \approx 4x^2/0.500$

Action: Multiply by 0.500, divide by four, then take the nonnegative square root.

After: $x \approx \sqrt{(0.2 \times 0.500/4)} = 0.158114$

Why: The defined forward extent is nonnegative.

Step 3

Before: x estimate 0.158114.

Action: Calculate the estimated depletion fraction.

After: $x/0.500 \times 100\% = 31.62\%$

Why: Compare this with the stated 5% screen.

Step 4

Before: Depletion 31.62%.

Action: Decide whether the shortcut is suitable.

After: The screen fails; use the full quadratic.

Why: The full solution gives $x = 0.13507811$.

$K \approx 4x^2/0.500$ gives $x \approx \sqrt{(0.200 \times 0.500/4)} = 0.158114$. Depletion = $0.158114/0.500 \times 100\% = 31.6\%$. The screen fails; use the complete quadratic. A small K alone is insufficient justification.

$K \approx 4x^2/0.500$ gives $x \approx \sqrt{(0.200 \times 0.500/4)} = 0.158114$.

Depletion = $0.158114/0.500 \times 100\% = 31.6\%$.

The screen fails; use the complete quadratic.

A small K alone is insufficient justification.

What to look for

- Uses the stated physical or chemical relationship.

- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 32

At another supplied temperature $K = 0.000200$. Initial N_2O_4 is 0.500 and NO_2 zero. Test the same approximation and compare with the complete solution.

Answer and working

Step 1

Before: $K = 4x^2/(0.500 - x)$

Action: Assume x is small relative to 0.500.

After: $K \approx 4x^2/0.500$

Why: This is a hypothesis to test, not an established equality.

Step 2

Before: $K \approx 4x^2/0.500$

Action: Multiply by 0.500, divide by four, then take the nonnegative square root.

After: $x \approx \sqrt{(0.0002 \times 0.500/4)} = 0.005000$

Why: The defined forward extent is nonnegative.

Step 3

Before: x estimate 0.005000.

Action: Calculate the estimated depletion fraction.

After: $x/0.500 \times 100\% = 1.00\%$

Why: Compare this with the stated 5% screen.

Step 4

Before: Depletion 1.00%.

Action: Decide whether the shortcut is suitable.

After: The screen passes; assess the required numerical precision too.

Why: The full solution gives $x = 0.00497506$.

Step 5

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 6

Before: $[\text{NO}_2] = 0$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0^2 = 0$

Why: Square the whole concentration; do not multiply it by two.

Step 7

Before: Product square 0; reactant 0.5

Action: Divide the product square by reactant concentration.

After: $Q = 0/0.5 = 0$

Why: Use the current values to calculate Q.

Step 8

Before: $Q = 0$; $K = 0.0002$

Action: Compare Q with the reference at this temperature.

After: Q is below K: net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

Step 9

Before: The quotient determines the net reaction direction.

Action: Define nonnegative x as N_2O_4 consumed.

After: $[\text{N}_2\text{O}_4] = 0.5 - x$; $[\text{NO}_2] = 0 + 2x$

Why: The balanced equation gives one-to-two concentration changes.

Step 10

Before: Every final concentration must be nonnegative.

Action: Set the extent bounds.

After: $0 \leq x \leq 0.5$

Why: Reject roots that violate these bounds or give zero denominator at finite K.

Step 11

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute both equilibrium expressions.

After: $0.0002 = (0 + 2x)^2/(0.5 - x)$

Why: Square the entire numerator bracket.

Step 12

Before: $0.0002 = (0 + 2x)^2/(0.5 - x)$

Action: Multiply both sides by $0.5 - x$.

After: $0.0002(0.5 - x) = (0 + 2x)^2$

Why: The denominator factor reduces to one.

Step 13

Before: $(0 + 2x)^2$

Action: Expand the square, including its middle term.

After: $0 + 0x + 4x^2$

Why: Use $u^2 \pm 2uv + v^2$; here v is $2x$.

Step 14

Before: $0.0002(0.5 - x)$

Action: Distribute K to both terms.

After: $0.0001 - 0.0002x$

Why: Both the constant term and the x term are multiplied by K.

Step 15

Before: $0 + 0x + 4x^2 = 0.0001 - 0.0002x$

Action: Subtract 0.0001 from both sides.

After: $-0.0001 + 0x + 4x^2 = -0.0002x$

Why: The matching constant on the right sums to zero.

Step 16

Before: The right side contains $-0.0002x$.

Action: Add $0.0002x$ on both sides.

After: $4x^2 + 0.0002x - 0.0001 = 0$

Why: Combine the x coefficients; the opposite right-side x terms sum to zero.

Step 17

Before: $4x^2 + 0.0002x - 0.0001 = 0$

Action: Read the quadratic coefficients.

After: $a = 4$; $b = 0.0002$; $c = -0.0001$

Why: Retain each coefficient sign.

Step 18

Before: Discriminant $= b^2 - 4ac$

Action: Substitute and calculate.

After: $(0.0002)^2 - 4 \times 4 \times (-0.0001) = 0.00160004$

Why: Bracket a negative coefficient when substituting.

Step 19

Before: $x = (-b \pm \sqrt{b^2 - 4ac})/(2a)$

Action: Substitute into the quadratic formula.

After: $x = (-(0.0002) \pm \sqrt{0.00160004})/8$

Why: Calculate both signs; the denominator is two times four.

Step 20

Before: Both signs of the formula are required.

Action: Calculate both numerical roots.

After: $x = 0.00497506$ or -0.00502506

Why: Use the physical constraints to choose the valid root.

Step 21

Before: $0 \leq x \leq 0.5$

Action: Reject $x = -0.00502506$.

After: Use $x = 0.00497506$

Why: The rejected value violates the extent bounds and gives a negative species concentration.

Step 22

Before: Use the valid extent in both species.

Action: Calculate final concentrations.

After: $[\text{N}_2\text{O}_4] = 0.495025$; $[\text{NO}_2] = 0.00995012$

Why: Keep guard digits while checking the solution.

Step 23

Before: Proposed final concentrations are now known.

Action: Check the quotient and conserved atoms.

After: $Q = 0.00995012^2/0.495025 \approx 0.0002$; $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1$

Why: Both the equilibrium ratio and starting atom inventory agree.

$x \approx \sqrt{(0.000200 \times 0.500/4)} = 0.00500$. Depletion estimate 1.00% passes the stated screen. Full quadratic $4x^2 + 0.000200x - 0.000100 = 0$ gives positive $x = 0.00497506$. Final $\text{N}_2\text{O}_4 = 0.495025$ and $\text{NO}_2 = 0.00995012$.

Assess whether approximate accuracy suits the purpose.

$x \approx \sqrt{(0.000200 \times 0.500/4)} = 0.00500$.

Depletion estimate 1.00% passes the stated screen.

Full quadratic $4x^2 + 0.000200x - 0.000100 = 0$ gives positive $x = 0.00497506$.

Final $\text{N}_2\text{O}_4 = 0.495025$ and $\text{NO}_2 = 0.00995012$.

Assess whether approximate accuracy suits the purpose.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 33

A piston halves volume at fixed temperature from equilibrium concentrations both 0.200. Find immediate and final concentrations.

Answer and working

Step 1

Before: Amount is unchanged during rapid compression.

Action: Divide volume by two.

After: Both concentrations immediately become 0.400

Why: Concentration equals amount divided by volume.

Step 2

Before: $Q = 0.400^2/0.400$

Action: Calculate and compare.

After: $Q = 0.400 > K = 0.200$

Why: K remains unchanged because temperature is unchanged.

Step 3

Before: Net change is reverse.

Action: Use +x and -2x.

After: $[N_2O_4] = 0.400 + x$; $[NO_2] = 0.400 - 2x$

Why: $0 \leq x \leq 0.200$.

Step 4

Before: $0.200 = (0.400 - 2x)^2/(0.400 + x)$

Action: Multiply by the denominator and expand.

After: $0.160 - 1.600x + 4x^2 = 0.0800 + 0.200x$

Why: The middle term of the square remains essential.

Step 5

Before: $0.160 - 1.600x + 4x^2 = 0.0800 + 0.200x$

Action: Subtract the right expression from both sides.

After: $4x^2 - 1.800x + 0.0800 = 0$

Why: Both sides undergo the same operations.

Step 6

Before: $a = 4$; $b = -1.800$; $c = 0.0800$

Action: Use the quadratic formula.

After: $x = (1.800 \pm \sqrt{(3.240 - 1.280)})/8 = 0.0500$ or 0.400

Why: The second root exceeds 0.200 and gives negative NO_2 .

Step 7

Before: Valid $x = 0.0500$

Action: Substitute and check.

After: $[\text{N}_2\text{O}_4] = 0.450$; $[\text{NO}_2] = 0.300$; $Q = 0.300^2/0.450 = 0.200$

Why: The new NO_2 concentration exceeds its original 0.200 even though reaction adjusted leftwards.

Immediate concentrations both 0.400 . $Q = 0.400 > K$, so let x be N_2O_4 formed. $(0.400 - 2x)^2 = 0.200(0.400 + x)$.

Collect $4x^2 - 1.800x + 0.0800 = 0$. Roots 0.0500 and 0.400 ; reject the latter because NO_2 becomes negative.

Final $\text{N}_2\text{O}_4 = 0.450$ and $\text{NO}_2 = 0.300$. Check $0.300^2/0.450 = 0.200$. K is unchanged.

Immediate concentrations both 0.400 .

$Q = 0.400 > K$, so let x be N_2O_4 formed.

$(0.400 - 2x)^2 = 0.200(0.400 + x)$.

Collect $4x^2 - 1.800x + 0.0800 = 0$.

Roots 0.0500 and 0.400 ; reject the latter because NO_2 becomes negative.

Final $\text{N}_2\text{O}_4 = 0.450$ and $\text{NO}_2 = 0.300$.

Check $0.300^2/0.450 = 0.200$.

K is unchanged.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use Q versus K to choose the direction before the ICE table.

Write equilibrium concentrations using one extent: reactant changes by x , product by twice x .

Multiply the quotient equation by its denominator on both sides, expand and collect the quadratic. Test both roots before reporting concentrations.

Question 34

A piston doubles volume from equilibrium N_2O_4 0.450 and NO_2 0.300 at fixed temperature. Find immediate and new equilibrium values.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.15$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.15^2 = 0.0225$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.0225; reactant 0.225

Action: Divide the product square by reactant concentration.

After: $Q = 0.0225/0.225 = 0.1$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.1$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is below K: net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

Step 5

Before: The quotient determines the net reaction direction.

Action: Define nonnegative x as N_2O_4 consumed.

After: $[\text{N}_2\text{O}_4] = 0.225 - x$; $[\text{NO}_2] = 0.15 + 2x$

Why: The balanced equation gives one-to-two concentration changes.

Step 6

Before: Every final concentration must be nonnegative.

Action: Set the extent bounds.

After: $0 \leq x \leq 0.225$

Why: Reject roots that violate these bounds or give zero denominator at finite K.

Step 7

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute both equilibrium expressions.

After: $0.2 = (0.15 + 2x)^2/(0.225 - x)$

Why: Square the entire numerator bracket.

Step 8

Before: $0.2 = (0.15 + 2x)^2/(0.225 - x)$

Action: Multiply both sides by $0.225 - x$.

After: $0.2(0.225 - x) = (0.15 + 2x)^2$

Why: The denominator factor reduces to one.

Step 9

Before: $(0.15 + 2x)^2$

Action: Expand the square, including its middle term.

After: $0.0225 + 0.6x + 4x^2$

Why: Use $u^2 \pm 2uv + v^2$; here v is $2x$.

Step 10

Before: $0.2(0.225 - x)$

Action: Distribute K to both terms.

After: $0.045 - 0.2x$

Why: Both the constant term and the x term are multiplied by K.

Step 11

Before: $0.0225 + 0.6x + 4x^2 = 0.045 - 0.2x$

Action: Subtract 0.045 from both sides.

After: $-0.0225 + 0.6x + 4x^2 = -0.2x$

Why: The matching constant on the right sums to zero.

Step 12

Before: The right side contains $-0.2x$.

Action: Add $0.2x$ on both sides.

After: $4x^2 + 0.8x - 0.0225 = 0$

Why: Combine the x coefficients; the opposite right-side x terms sum to zero.

Step 13

Before: $4x^2 + 0.8x - 0.0225 = 0$

Action: Read the quadratic coefficients.

After: $a = 4$; $b = 0.8$; $c = -0.0225$

Why: Retain each coefficient sign.

Step 14

Before: Discriminant $= b^2 - 4ac$

Action: Substitute and calculate.

After: $(0.8)^2 - 4 \times 4 \times (-0.0225) = 1$

Why: Bracket a negative coefficient when substituting.

Step 15

Before: $x = (-b \pm \sqrt{b^2 - 4ac})/(2a)$

Action: Substitute into the quadratic formula.

After: $x = (-(0.8) \pm \sqrt{1})/8$

Why: Calculate both signs; the denominator is two times four.

Step 16

Before: Both signs of the formula are required.

Action: Calculate both numerical roots.

After: $x = 0.025$ or -0.225

Why: Use the physical constraints to choose the valid root.

Step 17

Before: $0 \leq x \leq 0.225$

Action: Reject $x = -0.225$.

After: Use $x = 0.025$

Why: The rejected value violates the extent bounds and gives a negative species concentration.

Step 18

Before: Use the valid extent in both species.

Action: Calculate final concentrations.

After: $[\text{N}_2\text{O}_4] = 0.2$; $[\text{NO}_2] = 0.2$

Why: Keep guard digits while checking the solution.

Step 19

Before: Proposed final concentrations are now known.

Action: Check the quotient and conserved atoms.

After: $Q = 0.2^2/0.2 \approx 0.2$; $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 0.6$

Why: Both the equilibrium ratio and starting atom inventory agree.

Immediate values 0.225 and 0.150 give $Q = 0.100 < K$. Forward changes $-x$ and $+2x$ give $(0.150 + 2x)^2 = 0.200(0.225 - x)$. Collect $4x^2 + 0.800x - 0.0225 = 0$. Roots 0.0250 and -0.225 ; reject negative forward extent. Final concentrations both 0.200.

Immediate values 0.225 and 0.150 give $Q = 0.100 < K$.

Forward changes $-x$ and $+2x$ give $(0.150 + 2x)^2 = 0.200(0.225 - x)$.

Collect $4x^2 + 0.800x - 0.0225 = 0$.

Roots 0.0250 and -0.225 ; reject negative forward extent.

Final concentrations both 0.200.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use Q versus K to choose the direction before the ICE table.

Write equilibrium concentrations using one extent: reactant changes by x , product by twice x .

Multiply the quotient equation by its denominator on both sides, expand and collect the quadratic. Test both roots before reporting concentrations.

Question 35

At fixed volume and temperature, a feed raises NO_2 from 0.200 to 0.400 while N_2O_4 stays 0.200. Must all added product disappear? Calculate the final composition. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.4$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.4^2 = 0.16$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.16; reactant 0.2

Action: Divide the product square by reactant concentration.

After: $Q = 0.16/0.2 = 0.8$

Why: Use the current values to calculate Q .

Step 4

Before: $Q = 0.8$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is above K : net reverse change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K .

Step 5

Before: The quotient determines the net reaction direction.

Action: Define nonnegative x as N_2O_4 formed.

After: $[\text{N}_2\text{O}_4] = 0.2 + x$; $[\text{NO}_2] = 0.4 - 2x$

Why: The balanced equation gives one-to-two concentration changes.

Step 6

Before: Every final concentration must be nonnegative.

Action: Set the extent bounds.

After: $0 \leq x \leq 0.2$

Why: Reject roots that violate these bounds or give zero denominator at finite K.

Step 7

Before: $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Substitute both equilibrium expressions.

After: $0.2 = (0.4 - 2x)^2/(0.2 + x)$

Why: Square the entire numerator bracket.

Step 8

Before: $0.2 = (0.4 - 2x)^2/(0.2 + x)$

Action: Multiply both sides by $0.2 + x$.

After: $0.2(0.2 + x) = (0.4 - 2x)^2$

Why: The denominator factor reduces to one.

Step 9

Before: $(0.4 - 2x)^2$

Action: Expand the square, including its middle term.

After: $0.16 - 1.6x + 4x^2$

Why: Use $u^2 \pm 2uv + v^2$; here v is $2x$.

Step 10

Before: $0.2(0.2 + x)$

Action: Distribute K to both terms.

After: $0.04 + 0.2x$

Why: Both the constant term and the x term are multiplied by K.

Step 11

Before: $0.16 - 1.6x + 4x^2 = 0.04 + 0.2x$

Action: Subtract 0.04 from both sides.

After: $0.12 - 1.6x + 4x^2 = 0.2x$

Why: The matching constant on the right sums to zero.

Step 12

Before: The right side contains $+ 0.2x$.

Action: Subtract $0.2x$ on both sides.

After: $4x^2 - 1.8x + 0.12 = 0$

Why: Combine the x coefficients; the opposite right-side x terms sum to zero.

Step 13

Before: $4x^2 - 1.8x + 0.12 = 0$

Action: Read the quadratic coefficients.

After: $a = 4$; $b = -1.8$; $c = 0.12$

Why: Retain each coefficient sign.

Step 14

Before: Discriminant $= b^2 - 4ac$

Action: Substitute and calculate.

After: $(-1.8)^2 - 4 \times 4 \times (0.12) = 1.32$

Why: Bracket a negative coefficient when substituting.

Step 15

Before: $x = (-b \pm \sqrt{b^2 - 4ac})/(2a)$

Action: Substitute into the quadratic formula.

After: $x = (-(-1.8) \pm \sqrt{1.32})/8$

Why: Calculate both signs; the denominator is two times four.

Step 16

Before: Both signs of the formula are required.

Action: Calculate both numerical roots.

After: $x = 0.368614$ or 0.0813859

Why: Use the physical constraints to choose the valid root.

Step 17

Before: $0 \leq x \leq 0.2$

Action: Reject $x = 0.368614$.

After: Use $x = 0.0813859$

Why: The rejected value violates the extent bounds and gives a negative species concentration.

Step 18

Before: Use the valid extent in both species.

Action: Calculate final concentrations.

After: $[\text{N}_2\text{O}_4] = 0.281386$; $[\text{NO}_2] = 0.237228$

Why: Keep guard digits while checking the solution.

Step 19

Before: Proposed final concentrations are now known.

Action: Check the quotient and conserved atoms.

After: $Q = 0.237228^2/0.281386 \approx 0.2$; $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 0.8$

Why: Both the equilibrium ratio and starting atom inventory agree.

$Q = 0.400^2/0.200 = 0.800 > K$. Let x be N_2O_4 formed. $(0.400 - 2x)^2 = 0.200(0.200 + x)$. Expand and collect $4x^2 - 1.800x + 0.120 = 0$. Roots $(1.800 \pm \sqrt{1.320})/8 = 0.0813859$ or 0.368614 ; reject the latter because NO_2 becomes negative. Final $\text{N}_2\text{O}_4 = 0.281386$ and $\text{NO}_2 = 0.237228$. Added product is partly consumed; the original concentration need not return.

$Q = 0.400^2/0.200 = 0.800 > K$.

Let x be N_2O_4 formed.

$(0.400 - 2x)^2 = 0.200(0.200 + x)$.

Expand and collect $4x^2 - 1.800x + 0.120 = 0$.

Roots $(1.800 \pm \sqrt{1.320})/8 = 0.0813859$ or 0.368614 ; reject the latter because NO_2 becomes negative.

Final $\text{N}_2\text{O}_4 = 0.281386$ and $\text{NO}_2 = 0.237228$.

Added product is partly consumed; the original concentration need not return.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use Q versus K to choose the direction before the ICE table.

Write equilibrium concentrations using one extent: reactant changes by x , product by twice x .

Multiply the quotient equation by its denominator on both sides, expand and collect the quadratic. Test both roots before reporting concentrations.

Question 36

A separation step halves N_2O_4 from 0.200 to 0.100 while NO_2 remains 0.200 at fixed volume and temperature. Predict adjustment; evaluate the rule that removing reactant always favours forward reaction. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 2

Before: $[\text{NO}_2] = 0.2$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.2^2 = 0.04$

Why: Square the whole concentration; do not multiply it by two.

Step 3

Before: Product square 0.04; reactant 0.1

Action: Divide the product square by reactant concentration.

After: $Q = 0.04/0.1 = 0.4$

Why: Use the current values to calculate Q.

Step 4

Before: $Q = 0.4$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is above K: net reverse change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K.

$Q = 0.200^2/0.100 = 0.400 > K$. Net reverse change consumes NO_2 and forms N_2O_4 . Removing this reactant raised the quotient; the stated rule is false.

$Q = 0.200^2/0.100 = 0.400 > K$.

Net reverse change consumes NO_2 and forms N_2O_4 .

Removing this reactant raised the quotient; the stated rule is false.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 37

Compare inert-gas addition at constant volume and at constant total pressure, each at fixed temperature.

Answer and working

At fixed volume, reacting amounts and concentrations stay unchanged, so Q stays equal to K; no shift.

At constant total pressure, a movable piston expands volume.

If each reacting concentration is scaled by $f < 1$, new $Q = f^2[\text{NO}_2]^2/(f[\text{N}_2\text{O}_4]) = fK < K$.

Net forward change occurs in this ideal-gas model.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 38

At fixed volume, heating changes supplied K from 0.200 to 0.600 from equilibrium concentrations both 0.200. Find the new equilibrium.

Answer and working

Step 1

Before: The volume and amounts have not yet changed.

Action: Compare current Q with the new K.

After: $Q = 0.200 < \text{new } K = 0.600$

Why: Temperature changed K; reaction then changes concentrations.

Step 2

Before: Net change is forward.

Action: Use $-x$ and $+2x$.

After: $[\text{N}_2\text{O}_4] = 0.200 - x$; $[\text{NO}_2] = 0.200 + 2x$

Why: $0 \leq x \leq 0.200$.

Step 3

Before: $0.600 = (0.200 + 2x)^2 / (0.200 - x)$

Action: Multiply by the denominator and expand.

After: $0.120 - 0.600x = 0.0400 + 0.800x + 4x^2$

Why: The square has three terms.

Step 4

Before: $0.120 - 0.600x = 0.0400 + 0.800x + 4x^2$

Action: Add $0.600x$ and subtract 0.120 on both sides.

After: $4x^2 + 1.400x - 0.0800 = 0$

Why: Equal operations collect the quadratic.

Step 5

Before: $a = 4$; $b = 1.400$; $c = -0.0800$

Action: Calculate both roots.

After: $x = (-1.400 \pm \sqrt{(1.960 + 1.280)})/8 = 0.0500 \text{ or } -0.400$

Why: Reject the negative forward extent.

Step 6

Before: $x = 0.0500$

Action: Substitute and check.

After: $[\text{N}_2\text{O}_4] = 0.150$; $[\text{NO}_2] = 0.300$; $Q = 0.300^2/0.150 = 0.600$

Why: The new concentrations satisfy the new equilibrium constant.

Immediately $Q = 0.200 < \text{new } K = 0.600$. Let x be reactant consumed. $(0.200 + 2x)^2 = 0.600(0.200 - x)$. Collect $4x^2 + 1.400x - 0.0800 = 0$. Roots 0.0500 and -0.400 ; reject negative extent. Final $\text{N}_2\text{O}_4 = 0.150$ and $\text{NO}_2 = 0.300$. Check $0.300^2/0.150 = 0.600$.

Immediately $Q = 0.200 < \text{new } K = 0.600$.

Let x be reactant consumed.

$$(0.200 + 2x)^2 = 0.600(0.200 - x).$$

$$\text{Collect } 4x^2 + 1.400x - 0.0800 = 0.$$

Roots 0.0500 and -0.400 ; reject negative extent.

Final $\text{N}_2\text{O}_4 = 0.150$ and $\text{NO}_2 = 0.300$.

Check $0.300^2/0.150 = 0.600$.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Use Q versus K to choose the direction before the ICE table.

Write equilibrium concentrations using one extent: reactant changes by x , product by twice x .

Multiply the quotient equation by its denominator on both sides, expand and collect the quadratic. Test both roots before reporting concentrations.

Question 39

An engineer adds a suitable catalyst to improve equilibrium NO_2 yield at unchanged temperature. Evaluate.

Answer and working

The catalyst changes rates, not K or equilibrium composition.

A nonequilibrium mixture can approach equilibrium faster.

At equilibrium both rates increase while remaining equal.

Equilibrium product yield is unchanged under otherwise identical conditions.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K .

Question 40

After compression, sensor values are: before (0.200, 0.200), immediate (0.400, 0.400), final (0.450, 0.300), ordered N_2O_4 then NO_2 . Describe the curves and check the adjustment ratio.

Answer and working

Both curves jump upward when volume halves.

During chemical adjustment N_2O_4 rises gradually by 0.0500 while NO_2 falls by 0.100.

Change ratio is $+x$ and $-2x$.

Final plateaus show no net concentration change, not stopped reactions.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 41

At fixed calibrated optical path, absorbance is proportional to NO_2 concentration. It changes 0.200 to 0.400 immediately after compression, then to 0.300. Does the leftward adjustment make absorbance lower than originally?

Answer and working

Step 1

Before: Initial NO_2 concentration 0.200.

Action: Compare immediate 0.400 with the initial value.

After: $0.400/0.200 = 2.00$: absorbance doubles.

Why: The optical path and calibration are explicitly fixed.

Step 2

Before: Final NO_2 concentration 0.300.

Action: Compare final concentration with the initial value.

After: $0.300/0.200 = 1.50$: final absorbance is 1.5 times original.

Why: It decreased relative to the immediately compressed state but remains above the original.

Step 3

Before: A leftward chemical adjustment occurred.

Action: State the reference state when comparing colour.

After: Leftward adjustment does not imply a lower concentration than before compression.

Why: Volume changed the concentration before reaction adjustment.

Absorbance immediately doubles, then decreases to 1.5 times its original value. The leftward reaction reduces NO_2 relative to the compressed state, but final concentration exceeds the original. Do not confuse the reference states or assume an unchanged optical path in an uncalibrated vessel.

Absorbance immediately doubles, then decreases to 1.5 times its original value.

The leftward reaction reduces NO_2 relative to the compressed state, but final concentration exceeds the original.

Do not confuse the reference states or assume an unchanged optical path in an uncalibrated vessel.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Question 42

From initial N_2O_4 0.500 and NO_2 zero in a closed fixed-volume vessel, audit proposed final pairs A (0.200, 0.200), B (0.400, 0.200), C (0.364922, 0.270156). Check K and atoms independently. Use supplied $K = 0.200$ at the stated fixed temperature.

Answer and working

Step 1

Before: Initial N_2O_4 0.500; NO_2 zero.

Action: Count conserved nitrogen atoms per litre.

After: $2 \times 0.500 + 0 = 1.000$

Why: At fixed volume the atom inventory concentration stays constant.

Step 2

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 3

Before: $[\text{NO}_2] = 0.2$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.2^2 = 0.04$

Why: Square the whole concentration; do not multiply it by two.

Step 4

Before: Product square 0.04; reactant 0.2

Action: Divide the product square by reactant concentration.

After: $Q = 0.04/0.2 = 0.2$

Why: Use the current values to calculate Q.

Step 5

Before: $Q = 0.2$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is equal to K : dynamic equilibrium.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K .

Step 6

Before: Report A: $0.200 \text{ N}_2\text{O}_4$; 0.200 NO_2 .

Action: Check inventory independently.

After: $2 \times 0.200 + 0.200 = 0.600 \neq 1.000$

Why: A satisfies the equilibrium ratio but cannot conserve the original atoms.

Step 7

Before: $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 8

Before: $[\text{NO}_2] = 0.2$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.2^2 = 0.04$

Why: Square the whole concentration; do not multiply it by two.

Step 9

Before: Product square 0.04; reactant 0.4

Action: Divide the product square by reactant concentration.

After: $Q = 0.04/0.4 = 0.1$

Why: Use the current values to calculate Q .

Step 10

Before: $Q = 0.1$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is below K : net forward change.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K .

Step 11

Before: Report B: 0.400 N₂O₄; 0.200 NO₂.

Action: Check inventory independently.

After: $2 \times 0.400 + 0.200 = 1.000$

Why: B conserves atoms but has $Q = 0.100$ rather than K .

Step 12

Before: N₂O₄(g) $\rightleftharpoons$ 2NO₂(g)

Action: Write the current concentration quotient.

After: $Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Why: The coefficient two becomes an exponent.

Step 13

Before: $[\text{NO}_2] = 0.270156$

Action: Square the product concentration first.

After: $[\text{NO}_2]^2 = 0.270156^2 = 0.0729844$

Why: Square the whole concentration; do not multiply it by two.

Step 14

Before: Product square 0.0729844; reactant 0.364922

Action: Divide the product square by reactant concentration.

After: $Q = 0.0729844/0.364922 = 0.2$

Why: Use the current values to calculate Q .

Step 15

Before: $Q = 0.2$; $K = 0.2$

Action: Compare Q with the reference at this temperature.

After: Q is equal to K : dynamic equilibrium.

Why: At equilibrium the two reaction rates are equal; otherwise reaction changes the ratio towards K .

Step 16

Before: Report C retains the valid ICE concentrations.

Action: Check the inventory with guard digits.

After: $2 \times 0.364922 + 0.270156 = 1.000000$

Why: Only C matches both the starting atom inventory and the supplied equilibrium condition.

Initial nitrogen inventory: $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1.000$. A: $Q = 0.200$ but inventory 0.600, so impossible from this start. B: inventory 1.000 but $Q = 0.100$, so not at the supplied equilibrium. C: $Q \approx 0.200$ and inventory 1.000000; both conditions agree. Only C passes both checks.

Initial nitrogen inventory: $2[\text{N}_2\text{O}_4] + [\text{NO}_2] = 1.000$.

A: $Q = 0.200$ but inventory 0.600, so impossible from this start.

B: inventory 1.000 but $Q = 0.100$, so not at the supplied equilibrium.

C: $Q \approx 0.200$ and inventory 1.000000; both conditions agree.

Only C passes both checks.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K .

Question 43

With original $K = 0.200$, derive constants for $2\text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4$ and $2\text{N}_2\text{O}_4 \rightleftharpoons 4\text{NO}_2$. Explain why doubled coefficients do not give $2K$.

Answer and working

Step 1

Before: Original $K = [\text{NO}_2]^2/[\text{N}_2\text{O}_4]$

Action: Write the expression for the reversed equation.

After: Reverse constant = $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2$

Why: The new reactant and product roles swap; their balanced exponents stay attached to each formula.

Step 2

Before: $[\text{N}_2\text{O}_4]/[\text{NO}_2]^2$

Action: Recognise the reciprocal of the original ratio.

After: Reverse constant = $1/K$

Why: Multiplying the two ratios cancels matching concentration factors and gives one.

Step 3

Before: Reverse constant = $1/K$

Action: Substitute and calculate.

After: $1/0.200 = 5.00$

Why: Check: $5.00 \times 0.200 = 1.00$.

Step 4

Before: Balanced coefficients are now two and four.

Action: Apply each coefficient as an exponent.

After: New constant = $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2$

Why: A coefficient changes an exponent, not a multiplier outside the expression.

Step 5

Before: $[\text{NO}_2]^4/[\text{N}_2\text{O}_4]^2$

Action: Rewrite as the square of the original ratio.

After: $([\text{NO}_2]^2/[\text{N}_2\text{O}_4])^2 = K^2$

Why: Squaring a quotient squares its numerator and denominator.

Step 6

Before: New constant = K^2

Action: Substitute and square the full numerical constant.

After: $0.200^2 = 0.0400$

Why: Using the equilibrium pair 0.200 and 0.200: $0.200^4/0.200^2 = 0.0400$, confirming the new expression.

Reverse expression $[N_2O_4]/[NO_2]^2 = 1/K$, so constant 5.00. Doubled expression $[NO_2]^4/[N_2O_4]^2 = ([NO_2]^2/[N_2O_4])^2 = K^2 = 0.0400$. Doubling coefficients doubles exponents and squares the original constant.

Reverse expression $[N_2O_4]/[NO_2]^2 = 1/K$, so constant 5.00.

Doubled expression $[NO_2]^4/[N_2O_4]^2 = ([NO_2]^2/[N_2O_4])^2 = K^2 = 0.0400$.

Doubling coefficients doubles exponents and squares the original constant.

What to look for

- Uses the stated physical or chemical relationship.
- Shows the relevant working and reasoning.
- Checks the result against the original conditions.

Hints to offer

Identify whether the task concerns atoms, the quotient, an extent or changed conditions.

Write $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, then the relevant ratio or signed concentration changes.

Keep the coefficient two in powers and extents. Check bounds, conservation and Q against the appropriate temperature-dependent K.

Teaching notes

Focused current CH12-12 (Chemistry Stage 6 2017), not all Equilibrium and Acid Reactions. Exceeding means justified transfer and evaluation, not a guaranteed HSC band. All K values are supplied illustrative data; no real temperature is inferred. Ideal homogeneous gases, constant-temperature comparisons and classroom concentration convention are explicit. This is a paper/screen model, not instructions to handle toxic nitrogen dioxide. Excluded: thermodynamic activities, pressure-constant calculations requiring gas-law data, solubility equilibria and numerical rate laws. A suitable catalyst is a theoretical comparison, not a claim about a safe experimental catalyst for this mixture. Preserve existing tutor-confirmation logic. A visual model uses composition tokens, never fictional molecular geometry. Qualified review remains waived; effectiveness has not been evaluated.

Come back — fresh retrieval

Retrieval 1

For $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$, write the quotient and explain its exponent. With concentrations both 0.300, predict direction at $K = 0.200$.

$Q = [\text{NO}_2]^2/[\text{N}_2\text{O}_4] = 0.300$; coefficient two gives the exponent. $Q > K$, so net reverse change.

Retrieval 2

Initial N_2O_4 0.100 and NO_2 0.400: construct reverse ICE expressions and state root bounds.

Let x be N_2O_4 formed: $0.100 + x$ and $0.400 - 2x$, with $0 \leq x \leq 0.200$. Substitute into K and reject roots outside bounds.

Retrieval 3

Explain why an estimated extent of 0.0200 from initial reactant 0.100 fails a stated 5% small- x screen.

Depletion = $0.0200/0.100 \times 100\% = 20.0\%$; it exceeds the stated screen, so use the full equation.

Retrieval 4

Distinguish fixed-volume inert-gas addition from heating. Explain why checking K alone is insufficient. If original K is 0.200, find K for the doubled balanced equation.

Fixed-volume inert gas does not change reacting concentrations or Q in the ideal model; heating can change K . A final composition must match the starting atom inventory and imposed constraints. Doubling every balanced coefficient squares the expression, so new $K = 0.200^2 = 0.0400$.

Apply your understanding

At fixed temperature, multiply every equilibrium concentration by f through a rapid volume change. Derive the new quotient and use f to predict direction.

Numerator scales by f^2

Denominator scales by f

$$Q' = fK$$

Scale both concentrations, then the quotient

Numerator scales by f^2 Denominator scales by f $Q' = fK$

Answer and working

$Q' = (f[\text{NO}_2])^2 / (f[\text{N}_2\text{O}_4]) = f[\text{NO}_2]^2 / [\text{N}_2\text{O}_4] = fK$. If $f > 1$, $Q' > K$ and net reverse change follows. If $0 < f < 1$, $Q' < K$ and net forward change follows. If $f = 1$ there is no concentration perturbation. The cancelled factor is an algebraic scale factor; atoms are not cancelled.

Check common errors

Use $2[\text{NO}_2]$ rather than $[\text{NO}_2]^2$ in K .

The balanced coefficient is the exponent; show the expression before substitution.

Use $+x$ for NO_2 in the forward ICE table.

One N_2O_4 produces two NO_2 ; show $-x$ and $+2x$ and check atoms.

Accept every quadratic root.

Write concentration bounds before solving, then test both roots and both final concentrations.

Small K always permits neglecting x .

Compute the estimate and depletion ratio; compare with a declared tolerance and required precision.

Any increase in total pressure changes K .

State temperature, volume and reacting partial-pressure changes. K stays unchanged at fixed temperature.

A leftward shift restores the old concentrations.

Compare the original, immediate and final states separately; check K and atom inventory.

Lesson review

- Construct the quotient from the balanced equation and justify net direction.
- Solve forward and reverse ICE calculations, rejecting inadmissible roots.
- Test rather than assume a small- x approximation.
- Distinguish immediate changes from new equilibrium after volume or temperature changes.
- Evaluate claims and transformed equations using conservation and equilibrium checks.