Diploma Focused Unit Package

This package gets you ready for the Unit D questions on the diploma exam. Unit D is about 30% of the exam. You can work through it on your own. It teaches each idea from the start.

Part 1 is equilibrium systems (Cards 1 to 6). It is ready. **Part 2** is acids and bases (Cards 7 to 13). It is coming.

How to use this package

1. **Read the Big ideas page for a card first.** Each card names its idea.
2. **Read the card's steps and its worked example.**
3. **Do the questions on paper.** Use a calculator.
4. **Check your answers.** Every answer is worked. Find where your work first differs.
5. **Do the card check and show Mr F.** Then tick the card off on the checklist.

Stuck on a word? Look in Words to know. The start check, the Data Booklet page, the practice unit check and the exam-style question sets come with Part 2.

Checklist

Card	I can ...	Can do	Not yet
Part 1: equilibrium systems			
1	I can say if a system is at equilibrium, and I can read a graph of concentration against time.	☐	☐
2	I can write the equilibrium law expression for an equation, and I can say what the size of K_c means.	☐	☐
3	I can predict which way an equilibrium shifts after a stress, and say what happens to K_c.	☐	☐
4	I can read a graph of concentration against time to find the stress that was applied, the shift, and what happened to K_c.	☐	☐
5	I can use an ICE table to find every equilibrium concentration, and then find K_c.	☐	☐
6	I can use K_c to find a concentration at equilibrium, and an ICE table to find a concentration at the start.	☐	☐

Words to know

Equilibrium words

reversible reaction
A reaction that can go both ways. Reactants make products, and products make reactants again.

equilibrium arrow (⇌)
The double arrow in an equation. It tells you the reaction goes both ways.

forward reaction
The reaction read left to right: reactants make products.

reverse reaction
The reaction read right to left: products make reactants.

closed system
A container that nothing can enter or leave. A sealed flask is a closed system. An open beaker is not, if a gas can escape.

equilibrium
The state of a closed system when the forward and reverse reactions go at the same rate. Both reactions keep going, but nothing you can measure changes.

rate
How fast a reaction goes.

concentration, [ ]
The amount of a substance in each litre, in mol/L. Square brackets mean "the concentration of": $[NH_3(g)]$ is the concentration of ammonia.

equilibrium constant (K_c)
One number for a reaction at one temperature. It compares the products with the reactants at equilibrium. It has no units.

equilibrium law expression
The fraction that gives K_c: product concentrations on top, reactant concentrations on the bottom, each raised to the power of its coefficient.

coefficient
The number in front of a formula in a balanced equation. In $3H_2(g)$, the coefficient is 3.

homogeneous system
A system where every substance is in the same state, such as all gases.

heterogeneous system
A system with more than one state, such as a solid and a gas.

products favoured
At equilibrium there is much more product than reactant. K_c is large.

reactants favoured
At equilibrium there is much more reactant than product. K_c is small.

percent reaction

The percent of a reactant that has reacted when the system reaches equilibrium.

Shift words

Le Châtelier's principle
When a system at equilibrium is disturbed, it changes in the direction that undoes part of the disturbance.

stress
A change made to a system at equilibrium: a change in a concentration, the temperature, or the volume.

shift
What the system does after a stress. For a while one reaction is faster than the other, until a new equilibrium is reached.

shift toward the products
The forward reaction is faster for a while. More products form and reactants are used up. Also called a shift to the right.

shift toward the reactants
The reverse reaction is faster for a while. More reactants form and products are used up. Also called a shift to the left.

exothermic
A reaction that gives out energy. Energy is written on the product side.

endothermic
A reaction that takes in energy. Energy is written on the reactant side.

inert gas
A gas that does not react with anything in the system, such as argon or helium.

catalyst
A substance that makes a reaction faster and is not used up. It speeds up the forward and reverse reactions equally.

Calculation words

ICE table
A table with three rows: Initial, Change, Equilibrium. It keeps track of each concentration.

initial concentration
The concentration at the start, before any reaction.

change
How much a concentration goes up or down on the way to equilibrium. The changes follow the mole ratio.

equilibrium concentration
The concentration once the system is at equilibrium. Only these go into the equilibrium law expression.

mole ratio
The ratio of the coefficients in the balanced equation.

Big ideas

Idea 1: A reversible reaction and equilibrium

In Chemistry 20, a reaction went one way until a reactant ran out. Many reactions are not like that. They are **reversible**: the products can react to make the reactants again.

A reversible reaction is written with an **equilibrium arrow**, ⇌. Example: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + energy. Read left to right, it is the **forward reaction**. Read right to left, it is the **reverse reaction**.

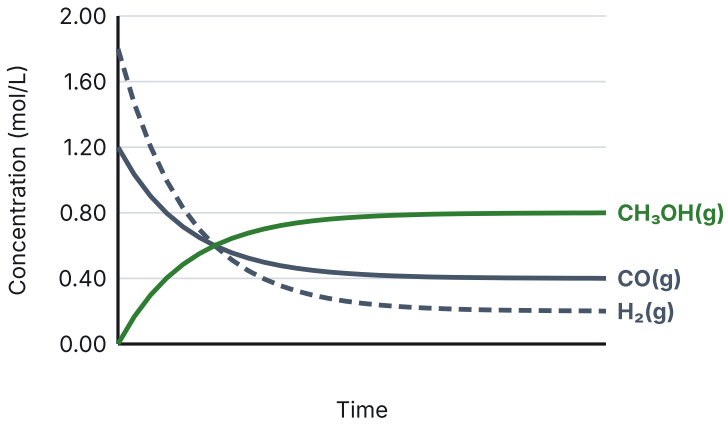
Put nitrogen and hydrogen in a sealed container. At first only the forward reaction happens, and it is fast. As ammonia builds up, the reverse reaction starts and gets faster. As the reactants are used, the forward reaction gets slower.

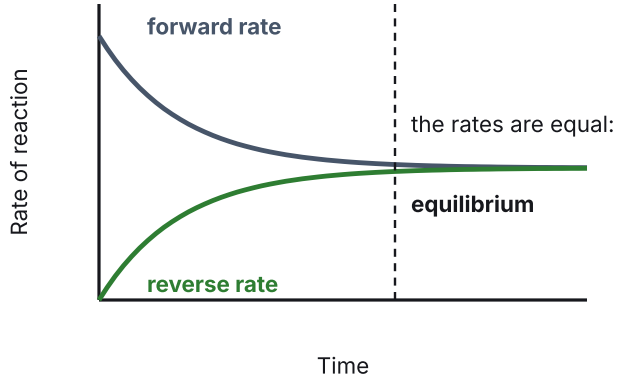
In the end the two rates are equal. Ammonia is made as fast as it breaks down. This state is **equilibrium**.

At equilibrium, four things are true. (1) The system is closed: nothing gets in or out. (2) The forward rate equals the reverse rate. (3) Both reactions are still going. (4) Nothing you can measure changes: each concentration, the colour, the pressure and the temperature stay constant.

Constant does not mean equal. At equilibrium the concentrations stop changing. They are almost never equal to each other.

On a graph of concentration against time, equilibrium is where every line is **flat**.





Idea 2: The equilibrium law expression and K_c

For one reaction at one temperature, the equilibrium concentrations always fit one fraction. The value of the fraction is the **equilibrium constant**, K_c.

The fraction is the **equilibrium law expression**. Products go on top. Reactants go on the bottom. Each concentration is raised to the power of its coefficient.

For $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + energy: $K_c = \frac{[NH_3(g)]^2}{[N_2(g)][H_2(g)]^3}$. The energy term is not in the expression.

What goes in: gases, (g), and dissolved particles, (aq). **What stays out:** pure solids, (s), and pure liquids, (l). Their concentrations cannot change. One exception: when **every** substance in the equation is a liquid, they all go in.

What the size of K_c means. A very large K_c, such as 10^8, means the top of the fraction is much bigger: products are favoured. A very small K_c, such as 10^{-8}, means reactants are favoured.

A K_c close to 1 is only a rough guide. When the two sides of the equation have different numbers of particles, a K_c a little above 1 does not prove there is more product.

K_c has no units. K_c changes only when the temperature changes.

Idea 3: Le Châtelier's principle: every stress in one table

Le Châtelier's principle: when a system at equilibrium is disturbed, it shifts in the direction that undoes part of the disturbance.

Treat energy like a substance. In an **exothermic** reaction, energy is a product. In an **endothermic** reaction, energy is a reactant.

Stress	What the system does	K_c
A reactant is added	Shifts toward the products, to use some of it up	No change
A reactant is removed	Shifts toward the reactants, to replace some of it	No change
A product is added	Shifts toward the reactants	No change
A product is removed	Shifts toward the products	No change
The temperature is raised	Shifts away from the energy term, to use up energy	**Changes**
The temperature is lowered	Shifts toward the energy term, to replace energy	**Changes**
The volume is made smaller (the pressure goes up)	Shifts toward the side with fewer moles of gas	No change

The volume is made larger (the pressure goes down)	Shifts toward the side with more moles of gas	No change
The volume changes, and both sides have the same moles of gas	No shift	No change
An inert gas is added to a container of fixed volume	No shift	No change
A catalyst is added	No shift	No change
More of a pure solid or pure liquid is added	No shift	No change

Three ways to raise the pressure, and they are not the same. (1) Make the volume smaller: the system shifts toward the side with fewer moles of gas. (2) Add more of a gas that is in the equation: the system shifts away from that gas. (3) Add an inert gas: no shift, because no concentration in the expression changed.

Hidden stresses. Sometimes the substance added is not in the equation. Ask what it removes. A base, such as NaOH(aq), removes $H^+(aq)$ or $H_3O^+(aq)$. An acid removes $OH^-(aq)$. Silver ions, $Ag^+(aq)$, remove $Cl^-(aq)$ as solid AgCl(s).

Only a temperature change changes K_c. If the shift caused by the temperature change is toward the products, K_c goes up. If it is toward the reactants, K_c goes down.

Idea 4: Graphs of an equilibrium being disturbed

The exam shows a stress on a graph of concentration against time. The system here is making methanol: $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ + energy.

Flat lines mean equilibrium. A dashed line marks the moment of the stress. Look at what the lines do **at** the dashed line.

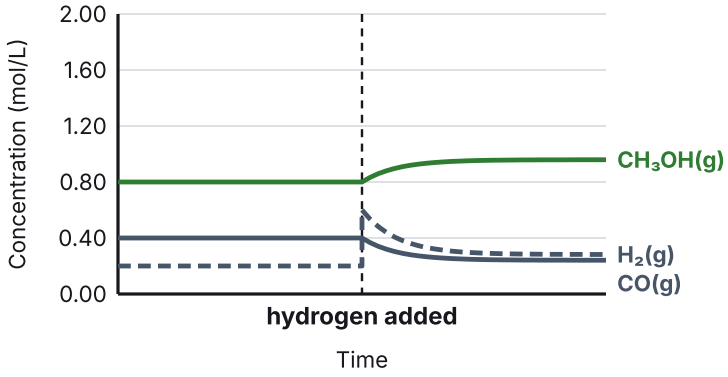
One line jumps straight up or down: that substance was added (up) or removed (down). The other lines do not jump. They curve.

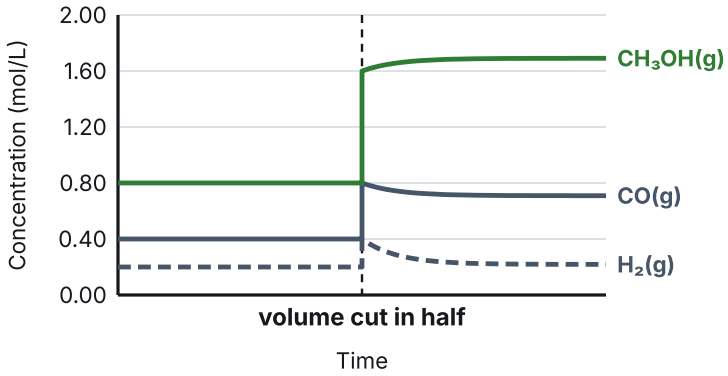
Every line jumps together: the volume was changed. All up: the volume was made smaller. All down: the volume was made larger.

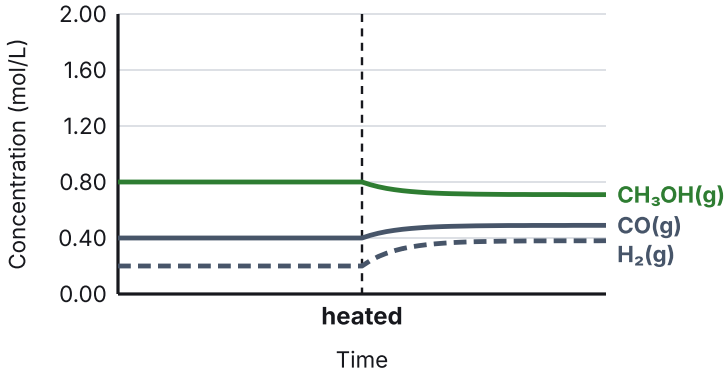
No line jumps, but all of them curve: the temperature was changed. K_c is now different.

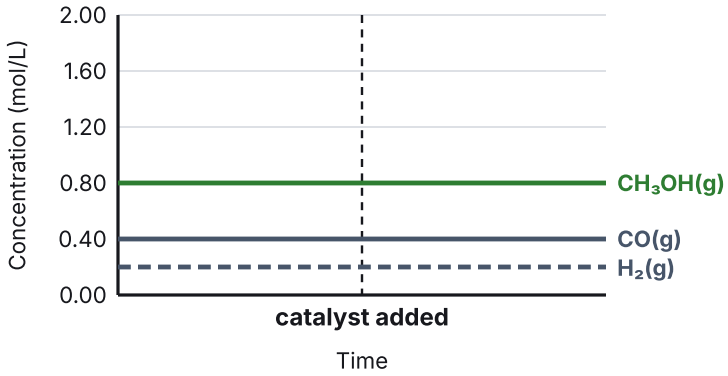
Nothing changes: a catalyst or an inert gas was added.

The **shift** is the curved part after the dashed line. A product line that curves up shows a shift toward the products.









Idea 5: The ICE table

An **ICE table** keeps track of each concentration. **I** is the initial concentration. **C** is the change. **E** is the equilibrium concentration. Every value is in mol/L.

If you are given moles and a volume, divide first: concentration = moles ÷ litres.

The **Change** row is the only row that follows the mole ratio. If the equation has 1 N_2, 3 H_2 and 2 NH_3, the changes are in the ratio 1 : 3 : 2.

If a substance is not mentioned at the start, its initial concentration is 0.

One side goes down and the other side goes up. If the reaction starts with no products, the reactants go down.

Only the **Equilibrium** row goes into the equilibrium law expression.

	$N_2(g)$	+	$3H_2(g)$	⇌	$2NH_3(g)$
Initial	0.500		1.50		0
Change	**−0.100**		**−0.300**		**+0.200**
Equilibrium	0.400		1.20		0.200

The Change row follows the mole ratio 1 : 3 : 2.
Reactants go down (−). Products go up (+). All values are in mol/L.

Card 1: Is the system at equilibrium?

I can say if a system is at equilibrium, and I can read a graph of concentration against time.

How to spot it on the diploma

- "Which of the following observations shows that the system has reached equilibrium?"
- "Which statement about a system at equilibrium is true?"
- A graph or a table of concentrations over time, and you must say when equilibrium is reached.

The steps

1. **Check that the system is closed.** A sealed container is closed. If a gas can escape, the system cannot reach equilibrium.
2. **Look for a property that has stopped changing.** Colour, pressure, concentration, pH or temperature. On a graph, the lines are flat.
3. **Remember what is still happening.** The forward and reverse reactions are both still going, at equal rates.
4. **Do not use the wrong signs.** Equal concentrations do not show equilibrium. Constant mass does not show equilibrium: the mass of a closed system never changes.

Worked example

Colourless $N_2O_4(g)$ is sealed in a glass tube. It reacts to make brown $NO_2(g)$: $N_2O_4(g)$ + energy $\rightleftharpoons$ $2NO_2(g)$. The gas turns pale brown, then darker brown. After 2 minutes the colour stops changing. Is the system at equilibrium after 2 minutes? How do you know?

> **Step 1**
> The tube is sealed, so the system is closed.
>
> **Step 2**
> The colour has stopped changing. Colour depends on the concentration of $NO_2(g)$, so the concentration is constant.
>
> **Step 3**
> $N_2O_4(g)$ is still breaking apart, and $NO_2(g)$ is still joining up again, at the same rate.
>
> **Answer**
> Yes. The system is closed and its colour is constant, so it is at equilibrium.

The common mistake

Saying the concentrations are **equal** at equilibrium. They are **constant**, not equal. Also: saying the reactions have stopped. They have not. They go at equal rates.

Your turn

Work on paper. Then check your answers.

QUESTION 1 · EASY · MULTIPLE CHOICE

Which statement is true for every chemical system at equilibrium?

A. The forward reaction and the reverse reaction have stopped.

B. The rate of the forward reaction equals the rate of the reverse reaction.

C. The concentration of the reactants equals the concentration of the products.

D. All of the reactants have been used up.

QUESTION 2 · MEDIUM · MULTIPLE CHOICE

Brown $NO_2(g)$ and colourless $N_2O_4(g)$ are in a sealed flask on a balance: $N_2O_4(g)$ + energy ⇌ $2NO_2(g)$. Which observation shows that the system has reached equilibrium?

A. The mass of the flask and its contents is constant.

B. The flask contains both $NO_2(g)$ and $N_2O_4(g)$.

C. The colour of the gas is constant.

D. The flask is sealed.

QUESTION 3 · MEDIUM · NUMERICAL RESPONSE

A student seals $N_2O_4(g)$ in a flask and measures the concentrations every 20 s.

Time (s)	0	20	40	60	80	100
$[N_2O_4(g)]$ (mol/L)	0.100	0.070	0.052	0.040	0.040	0.040
$[NO_2(g)]$ (mol/L)	0	0.060	0.096	0.120	0.120	0.120

The first time in the table at which the system is at equilibrium is _____ s.

Answer: [ ]

QUESTION 4 · MEDIUM · MULTIPLE CHOICE

When a system reaches equilibrium, the concentration of each substance is _i_, and the forward and reverse reactions _ii_.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	constant	have stopped
B.	constant	go at equal rates
C.	equal to the others	have stopped
D.	equal to the others	go at equal rates

QUESTION 5 · EXAM LEVEL · MULTIPLE CHOICE

A student makes four statements about a system at equilibrium.
I. The system is closed.
II. The reactants and products have equal concentrations.
III. The pressure of a gas system is constant.
IV. No particles are reacting.

The statements that are true are

A. I and III

B. I and IV

C. II and III

D. II and IV

CHALLENGE

A sealed bottle of pop holds this equilibrium: $CO_2(g) \rightleftharpoons CO_2(aq)$. You open the bottle and leave the cap off. Explain why the pop goes flat. Use the words “closed system”.

▼ **Hint**

What can leave the bottle now? Can the forward reaction still be matched by the reverse reaction?

▼ **Check your answers for Card 1**

Question 1: B. At equilibrium both reactions keep going at equal rates. The concentrations are constant, not equal, and reactants are still present.

Question 2: C. A constant colour means the concentration of $NO_2(g)$ has stopped changing. The mass of a sealed flask is always constant, even before equilibrium. Having both gases, or a sealed flask, is needed

but does not show that the change has stopped.

Question 3: 60. Both concentrations change until 60 s. From 60 s on they stay at 0.040 mol/L and 0.120 mol/L. Constant concentrations show equilibrium, so the first time is 60 s.

Question 4: B. Each concentration stays constant. The reactions do not stop: they go at equal rates.

Question 5: A. I is true: equilibrium needs a closed system. III is true: measurable properties are constant. II is false: the concentrations are constant, not equal. IV is false: both reactions keep going.

Challenge. With the cap off, the system is no longer closed. CO_2(g) escapes into the room, so it cannot dissolve again. CO_2(aq) keeps leaving the liquid as gas, and nothing replaces it. The system cannot reach equilibrium, and the dissolved CO_2 slowly leaves until the pop is flat.

Card 1 check

Answer these three on paper and show Mr F. They tell you both if you are ready to move on.

1. State two things that are true about the rates of the forward and reverse reactions at equilibrium.
2. A sealed flask of gases has a constant mass. Does this show the system is at equilibrium? Explain.
3. On a graph of concentration against time, how do you see that equilibrium has been reached?

Need more? Read the Big ideas page again: Idea 1. Stuck on a word? Look in Words to know.

Card 2: Write the equilibrium law expression

I can write the equilibrium law expression for an equation, and I can say what the size of K_c means.

How to spot it on the diploma

- "The equilibrium law expression for this reaction is ..."
- An expression with letters for the powers, and you record the four powers as digits.
- "The value of K_c shows that the *i* are favoured."

The steps

1. **Check the equation is balanced.** You need the coefficients.
2. **Cross out every pure solid (s) and pure liquid (l).** They are not in the expression. Keep every (g) and (aq). If every substance is a liquid, keep them all.
3. **Write the products on top and the reactants on the bottom.** Use square brackets. Substances on the same side are multiplied.
4. **Turn each coefficient into a power.** $2NH_3(g)$ becomes $[NH_3(g)]^2$. A coefficient of 1 needs no power.
5. **Read the size of K_c, if asked.** Very large: products are favoured. Very small: reactants are favoured.

Worked example

Write the equilibrium law expression for $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$.

Step 1
The equation is balanced: 4 N, 12 H and 10 O on each side.

Step 2
Every substance is a gas. Nothing is crossed out. Here water is $H_2O(g)$, so it stays in.

Step 3
Products on top: $[NO(g)]$ and $[H_2O(g)]$. Reactants on the bottom: $[NH_3(g)]$ and $[O_2(g)]$.

Step 4
The coefficients 4, 6, 4 and 5 become powers.

Answer

$$K_c = \frac{[NO(g)]^4[H_2O(g)]^6}{[NH_3(g)]^4[O_2(g)]^5}$$

The common mistake

Putting a solid or a liquid in the expression. Check every state symbol. Also: writing the coefficient in front, as $2[NH_3(g)]$, when it must be a power, $[NH_3(g)]^2$.

Your turn

Work on paper. Then check your answers.

QUESTION 1 · EASY · MULTIPLE CHOICE

The equilibrium law expression for $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ is

A. $K_c = \dfrac{[PCl_3(g)][Cl_2(g)]}{[PCl_5(g)]}$

B. $K_c = \dfrac{[PCl_5(g)]}{[PCl_3(g)][Cl_2(g)]}$

C. $K_c = \dfrac{[PCl_3(g)] + [Cl_2(g)]}{[PCl_5(g)]}$

D. $K_c = [PCl_3(g)][Cl_2(g)][PCl_5(g)]$

QUESTION 2 · MEDIUM · MULTIPLE CHOICE

Limestone is heated in a closed kiln: $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$. The equilibrium law expression is

A. $K_c = \dfrac{[CaO(s)][CO_2(g)]}{[CaCO_3(s)]}$

B. $K_c = \dfrac{[CaCO_3(s)]}{[CaO(s)][CO_2(g)]}$

C. $K_c = [CO_2(g)]$

D. $K_c = \dfrac{1}{[CO_2(g)]}$

QUESTION 3 · MEDIUM · NUMERICAL RESPONSE

For the reaction $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$, the equilibrium law expression is $K_c = \dfrac{[N_2(g)]^a[H_2O(g)]^b}{[NH_3(g)]^c[O_2(g)]^d}$.

The values of *a*, *b*, *c* and *d* are _____, _____, _____ and _____. (Record all four digits in that order.)

Answer: [ ]

QUESTION 4 · MEDIUM · MULTIPLE CHOICE

In air at room temperature, $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ has a very small equilibrium constant, close to 10^{-30}. At equilibrium the __*i*__ are favoured, and the equilibrium law expression has [NO(g)] raised to the power __*ii*__.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	reactants	1
B.	reactants	2
C.	products	1
D.	products	2

QUESTION 5 · EXAM LEVEL · NUMERICAL RESPONSE

Carbon reacts with carbon dioxide in a closed furnace: $C(s) + CO_2(g) \rightleftharpoons 2CO(g)$. At equilibrium, [CO(g)] = 0.300 mol/L and $[CO_2(g)]$ = 0.0450 mol/L.

The value of the equilibrium constant is _____. (Record your three-digit answer.)

Answer: ☐

CHALLENGE

An ester is made from two liquids: $CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$. Every substance is a liquid. Write the equilibrium law expression, and explain why the liquids are not left out this time.

▼ **Hint**

Liquids are left out when they are pure. Are these liquids pure once they are mixed together?

▼ **Check your answers for Card 2**

Question 1: A. Products on top, multiplied. The reactant on the bottom. All coefficients are 1, so there are no powers.

Question 2: C. $CaCO_3(s)$ and CaO(s) are pure solids, so they are left out. Only the gas is left, and it is a product, so it is on top.

Question 3: 2643. Each power is the coefficient of that substance: N_2 is 2, H_2O is 6, NH_3 is 4 and O_2 is 3. Record 2643.

Question 4: B. A very small K_c means the top of the fraction is tiny: almost no NO(g) forms, so the reactants are favoured. The coefficient of NO(g) is 2, so its power is 2.

Question 5: 2.00. C(s) is a solid, so it is left out. $K_c = \frac{[CO(g)]^2}{[CO_2(g)]} = \frac{(0.300)^2}{0.0450} = 2.00$. K_c has no units.

Challenge. $K_c = \frac{[CH_3COOC_2H_5(l)][H_2O(l)]}{[CH_3COOH(l)][C_2H_5OH(l)]}$. The four liquids are mixed together, so none of them is pure. The concentration of each one changes as the reaction goes, so each one is in the expression.

Card 2 check

Answer these three on paper and show Mr F. They tell you both if you are ready to move on.

1. Write the equilibrium law expression for $2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$.
2. Write the equilibrium law expression for $NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$.
3. A reaction has $K_c = 2.5 \times 10^{12}$. Are the reactants or the products favoured?

Need more? Read the Big ideas page again: Idea 2. Stuck on a word? Look in Words to know.

Card 3: Predict which way an equilibrium shifts

I can predict which way an equilibrium shifts after a stress, and say what happens to K_c.

How to spot it on the diploma

- "Which change would increase the amount of product at equilibrium?"
- "When the volume of the container is decreased, the equilibrium shifts toward the *i*."
- A substance is added that is not in the equation. It is a hidden stress.
- "Record the numbers of the stresses that cause a shift toward the reactants."

The steps

1. **Write the energy term into the equation.** Exothermic: energy is a product. Endothermic: energy is a reactant.
2. **Name the stress as "more of" or "less of" something.** Heating is more energy. A base added is less $H^+(aq)$. Silver ions added is less $Cl^-(aq)$.
3. **Shift away from "more of". Shift toward "less of".** The system uses up part of what was added, or replaces part of what was removed.
4. **For a volume change, count the moles of gas on each side.** Smaller volume: shift toward the side with fewer moles of gas. Larger volume: toward the side with more. Equal on both sides: no shift.
5. **Know the three "no shift" cases.** A catalyst. An inert gas. More of a pure solid or liquid.
6. **Decide about K_c.** Only a temperature change changes it. Shift toward the products: K_c goes up. Toward the reactants: K_c goes down.

Every stress in one table

Stress	What the system does	K_c
A reactant is added	Shifts toward the products, to use some of it up	No change
A reactant is removed	Shifts toward the reactants, to replace some of it	No change
A product is added	Shifts toward the reactants	No change
A product is removed	Shifts toward the products	No change
The temperature is raised	Shifts away from the energy term, to use up energy	**Changes**

The temperature is lowered	Shifts toward the energy term, to replace energy	**Changes**
The volume is made smaller (the pressure goes up)	Shifts toward the side with fewer moles of gas	No change
The volume is made larger (the pressure goes down)	Shifts toward the side with more moles of gas	No change
The volume changes, and both sides have the same moles of gas	No shift	No change
An inert gas is added to a container of fixed volume	No shift	No change
A catalyst is added	No shift	No change
More of a pure solid or pure liquid is added	No shift	No change

Worked example

Methanol is made in a closed reactor: $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ + energy. The volume of the reactor is made smaller. Which way does the equilibrium shift, and what happens to K_c?

> **Step 1**
> The energy term is already there, on the product side. It is not needed for this stress.
>
> **Step 2**
> A smaller volume means a higher pressure. The stress is “more pressure”.
>
> **Steps 3 and 4**
> Count the moles of gas. Reactant side: 1 + 2 = 3. Product side: 1. The system lowers the pressure by making fewer moles of gas. It shifts toward the products.
>
> **Step 5**
> This is not a “no shift” case: the two sides have different moles of gas.
>
> **Step 6**
> The temperature did not change, so K_c does not change.
>
> **Answer**
> The equilibrium shifts toward the products. More $CH_3OH(g)$ forms. K_c stays the same.

The common mistake

Saying a volume or pressure change alters K_c. It does not. Only temperature changes K_c. Also: counting a solid, a liquid or a dissolved particle as a gas when you count moles of gas.

Your turn

Work on paper. Then check your answers.

QUESTION 1 · EASY · MULTIPLE CHOICE

Ammonia is made in a closed reactor: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + energy. More $N_2(g)$ is added. The equilibrium shifts toward the

A. products, and the concentration of $H_2(g)$ goes down

B. products, and the concentration of $H_2(g)$ goes up

C. reactants, and the concentration of $H_2(g)$ goes down

D. reactants, and the concentration of $H_2(g)$ goes up

QUESTION 2 · MEDIUM · MULTIPLE CHOICE

For $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + energy, the temperature is raised. The equilibrium shifts toward the _*i*_, and the value of K_C _*ii*_.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	products	increases
B.	products	stays the same
C.	reactants	decreases
D.	reactants	stays the same

QUESTION 3 · MEDIUM · MULTIPLE CHOICE

A closed cylinder holds this equilibrium: $PCl_5(g)$ + energy $\rightleftharpoons PCl_3(g) + Cl_2(g)$. The piston is pushed in, so the volume is smaller. The equilibrium shifts toward the _*i*_, and the value of K_C _*ii*_.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	products	increases
B.	products	stays the same
C.	reactants	decreases
D.	reactants	stays the same

QUESTION 4 · MEDIUM · MULTIPLE CHOICE

A solution holds yellow chromate ions and orange dichromate ions at equilibrium: $2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$. A few drops of NaOH(aq) are added. The solution becomes more

A. orange, because the equilibrium shifts toward the products

B. orange, because the equilibrium shifts toward the reactants

C. yellow, because the equilibrium shifts toward the products

D. yellow, because the equilibrium shifts toward the reactants

QUESTION 5 · MEDIUM · NUMERICAL RESPONSE

Blue $Cu^{2+}(aq)$ and green $CuCl_4^{2-}(aq)$ are at equilibrium in a beaker: $Cu^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CuCl_4^{2-}(aq)$. A student lists six changes.

1. Add NaCl(s), which dissolves
2. Add $AgNO_3(aq)$
3. Add $CuSO_4(s)$, which dissolves
4. Add NaOH(aq)
5. Add a catalyst
6. Add $NaNO_3(s)$, which dissolves

The two changes that shift the equilibrium toward the **reactants** are numbered _____ and _____. (Record the two digits, lowest first.)

Answer: ☐

QUESTION 6 · EXAM LEVEL · MULTIPLE CHOICE

A rigid steel tank holds $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + energy at equilibrium. Argon gas is pumped in. The volume and the temperature of the tank do not change. The total pressure in the tank __*i*__, and the equilibrium __*ii*__.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	increases	shifts toward the products
B.	increases	does not shift
C.	stays the same	shifts toward the products
D.	stays the same	does not shift

CHALLENGE

A company makes ammonia: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ + energy. Name three changes to the conditions that would each give more ammonia at equilibrium. Then explain why the company still uses a high temperature and a catalyst.

▼ **Hint**

Use the stress table. Then think about rate: how fast is a cold reaction?

▼ **Check your answers for Card 3**

Question 1: A. The stress is more $N_2(g)$, a reactant. The system shifts away from it, toward the products. The forward reaction uses $H_2(g)$, so its concentration goes down.

Question 2: C. Energy is a product. Heating is more energy, so the system shifts away from it, toward the reactants. A temperature change does change K_c. The shift is toward the reactants, so K_c decreases.

Question 3: D. Moles of gas: 1 on the reactant side, 2 on the product side. A smaller volume shifts the system toward fewer moles of gas, the reactants. The temperature is the same, so K_c stays the same.

Question 4: D. NaOH(aq) is not in the equation, so ask what it removes. $OH^-(aq)$ reacts with $H^+(aq)$ to make water. The stress is less $H^+(aq)$, a reactant. The system shifts toward the reactants to replace it. More yellow $CrO_4^{2-}(aq)$ forms.

Question 5: 24. Change 2: $Ag^+(aq)$ removes $Cl^-(aq)$ as AgCl(s). Less of a reactant, so the shift is toward the reactants. Change 4: $OH^-(aq)$ removes $Cu^{2+}(aq)$ as solid $Cu(OH)_2(s)$ (see the solubility table in the Data Booklet). Less of a reactant again, so the shift is toward the reactants. Changes 1 and 3 add a reactant, so they shift toward the products. Changes 5 and 6 cause no shift: a catalyst never does, and $Na^+(aq)$ and $NO_3^-(aq)$ are not in the equation and remove nothing.

Question 6: B. More gas in the same volume means a higher total pressure. But argon is inert and is not in the equilibrium law expression. The concentrations of $N_2(g)$, $H_2(g)$ and $NH_3(g)$ did not change, so there is no shift.

Challenge. More ammonia at equilibrium: (1) add more $N_2(g)$ or $H_2(g)$; (2) remove $NH_3(g)$ as it forms; (3) use a smaller volume (higher pressure), because there are 4 moles of gas on the reactant side and 2 on the product side; (4) use a lower temperature, because energy is a product. A low temperature gives more ammonia, but the reaction is then very slow. So the company uses a fairly high temperature and a catalyst to reach equilibrium quickly. The catalyst does not change how much ammonia there is at equilibrium.

Card 3 check

Answer these three on paper and show Mr F. They tell you both if you are ready to move on.

1. For $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ + energy, which way does the equilibrium shift when the volume is made larger?
2. For the same system, what happens to K_c when the temperature is lowered?

3. Name two changes that never cause a shift.

Need more? Read the Big ideas page again: Idea 3. Stuck on a word? Look in Words to know.

Card 4: Read a graph to find the stress

I can read a graph of concentration against time to find the stress that was applied, the shift, and what happened to K_c.

How to spot it on the diploma

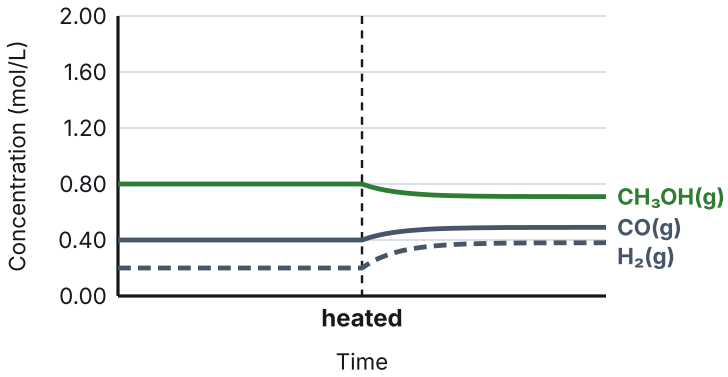
- A graph of concentration against time with a dashed line at a labelled time.
- "The change made at time *p* was …"
- "The value of the equilibrium constant at time *p* is …" You read the values from the graph.

The steps

1. **Find the dashed line. Look at the lines right at it.** Do the lines jump straight up or down, or not?
2. **Name the kind of stress from the jumps. One line jumps:** that substance was added (up) or removed (down). **All lines jump together:** the volume changed. All up is a smaller volume. All down is a larger volume. **No line jumps, but the lines curve:** the temperature changed.
3. **Find the shift from the curved parts after the dashed line.** Products curve up: toward the products. Products curve down: toward the reactants.
4. **For a temperature change, use the energy term.** A shift away from the energy term uses up energy: the system was heated. A shift toward the energy term replaces energy: the system was cooled.
5. **Decide about K_c.** It changes only for a temperature change. To find its value, put the values from a flat part into the equilibrium law expression.

Worked example

The system $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ + energy is at equilibrium in a closed reactor. A change is made at the dashed line.



What was the stress, and what happened to K_c?

Step 1
At the dashed line, no line jumps straight up or down.

Step 2
No jump, but every line curves. The stress was a temperature change.

Step 3
The product, $CH_3OH(g)$, curves down. The reactants curve up. The shift is toward the reactants.

Step 4
Energy is a product. The shift is away from the energy term, so the system is using up energy. The system was heated.

Step 5
The temperature changed, so K_c changed. The shift is toward the reactants, so K_c is now smaller.

Answer
The system was heated. The equilibrium shifted toward the reactants, and K_c decreased.

The common mistake

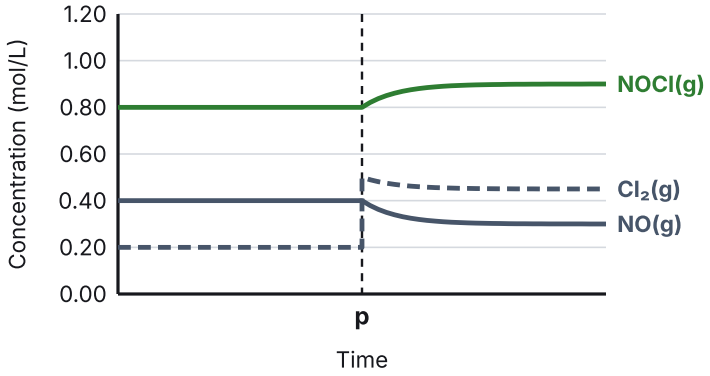
Reading the jump as the shift. The straight jump is the **stress**. The **shift** is the curve that comes after it. Also: expecting the lines to go back to their old values. They level off at new values.

Your turn

Work on paper. Then check your answers.

QUESTION 1 · EASY · MULTIPLE CHOICE

The system $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ + energy is at equilibrium in a closed container. A change is made at time *p*.



The change made at time *p* was that

A. $Cl_2(g)$ was added

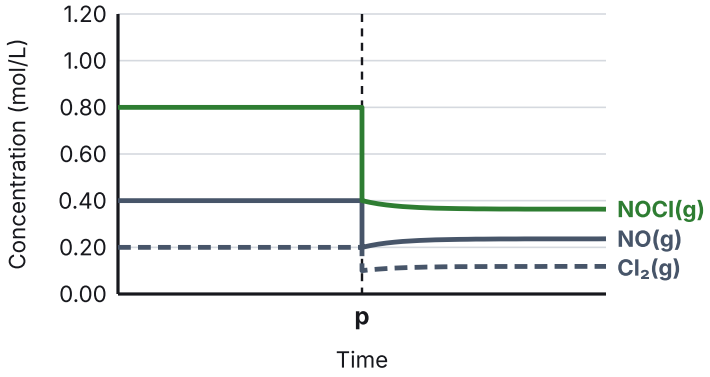
B. $Cl_2(g)$ was removed

C. the volume was made smaller

D. the temperature was raised

QUESTION 2 · MEDIUM · MULTIPLE CHOICE

The system $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ + energy is at equilibrium in a closed container. A change is made at time *p*.



The change made at time *p* was that

A. NOCl(g) was removed

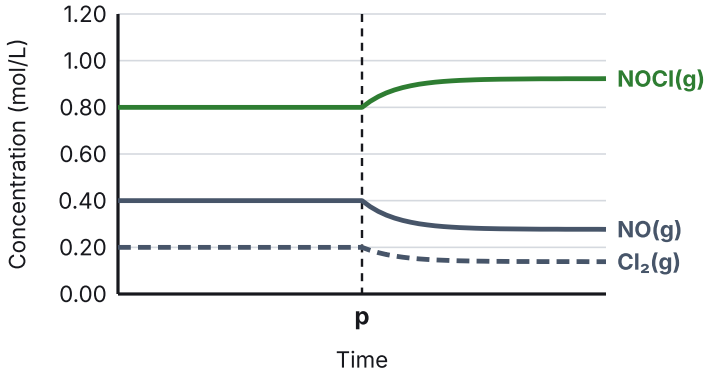
B. the volume of the container was made smaller

C. the volume of the container was made larger

D. the temperature was lowered

QUESTION 3 · MEDIUM · MULTIPLE CHOICE

The system $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ + energy is at equilibrium in a closed container. A change is made at time *p*.



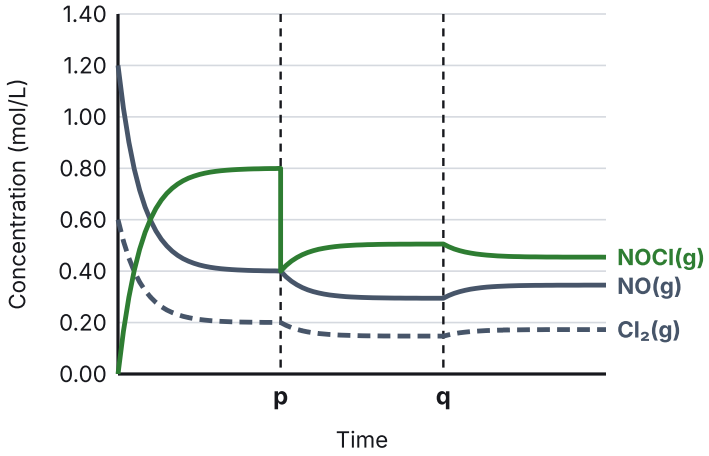
At time *p*, the temperature of the system was __*i*__, and the value of K_c after time *p* is __*ii*__ than before.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	raised	larger
B.	raised	smaller
C.	lowered	larger
D.	lowered	smaller

QUESTION 4 · MEDIUM · NUMERICAL RESPONSE

Use this graph to answer questions 4 and 5. NO(g) and $Cl_2(g)$ are put in a closed container: $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ + energy. Changes are made at time *p* and at time *q*.



Just before time *p*, the value of the equilibrium constant is _____. (Record your three-digit answer.)

Answer: [ ]

QUESTION 5 · EXAM LEVEL · MULTIPLE CHOICE

On the graph for question 4, the change made at time *p* was __*i*__, and the change made at time *q* was __*ii*__.

The statement above is completed by the information in row

Row	*i*	*ii*
A.	removing NOCl(g)	raising the temperature
B.	removing NOCl(g)	lowering the temperature
C.	making the volume larger	raising the temperature
D.	making the volume larger	lowering the temperature

CHALLENGE

Look again at the graph for question 4. Between time *p* and time *q* the lines become flat at about 0.51 mol/L for NOCl(g), 0.30 mol/L for NO(g) and 0.15 mol/L for $Cl_2(g)$. Show that K_c is still about 20. Then explain why it should be.

▼ Hint

Use the same equilibrium law expression as in question 4. What kind of stress was applied at time p?

▼ **Check your answers for Card 4**

Question 1: A. Only the $Cl_2(g)$ line jumps, and it jumps up. So $Cl_2(g)$ was added. After that, NO(g) and $Cl_2(g)$ curve down and NOCl(g) curves up: the shift is toward the products, away from the added reactant.

Question 2: C. All three lines drop at the same moment, so the volume was changed. Every concentration went down, so the volume was made larger. Then the system shifts toward the side with more moles of gas: the reactants (3 moles against 2). NO(g) and $Cl_2(g)$ curve up.

Question 3: C. No line jumps, so the stress was a temperature change. NOCl(g) curves up, so the shift is toward the products. That is toward the energy term, which replaces energy. So energy was removed: the system was cooled. A shift toward the products makes K_c larger.

Question 4: 20.0. Read the flat parts just before *p*: [NOCl(g)] = 0.80 mol/L, [NO(g)] = 0.40 mol/L, $[Cl_2(g)]$ = 0.20 mol/L. $K_c = \frac{[NOCl(g)]^2}{[NO(g)]^2[Cl_2(g)]} = \frac{(0.80)^2}{(0.40)^2(0.20)} = 20.0$.

Question 5: A. At *p*, only the NOCl(g) line jumps, and it jumps down: NOCl(g) was removed. At *q*, no line jumps, so the temperature changed. After *q*, NOCl(g) curves down: a shift toward the reactants, away from the energy term. The system does that when energy is added, so the temperature was raised.

Challenge. $K_c = \frac{(0.51)^2}{(0.30)^2(0.15)} = 19$, which is about 20. (The small difference comes from reading the graph to two digits.) The stress at *p* was a concentration change. The temperature did not change, so K_c must be the same. The concentrations are all different from before, but they fit the same fraction.

Card 4 check

Answer these three on paper and show Mr F. They tell you both if you are ready to move on.

1. On a graph, every line jumps straight up at the same moment. What was done?
2. On a graph, one line drops straight down and the others only curve. What was done?
3. On a graph, no line jumps, and the product line curves up. The reaction is exothermic. What was done, and what happened to K_c?

Need more? Read the Big ideas page again: Idea 4 · Idea 3. Stuck on a word? Look in Words to know.

Card 5: Use an ICE table to find K_c

I can use an ICE table to find every equilibrium concentration, and then find K_c.

How to spot it on the diploma

- You are given the initial amounts, and **one** concentration at equilibrium.
- "The value of the equilibrium constant is …"
- Moles and a volume are given, not concentrations.

The steps

1. **Write the balanced equation and draw an ICE table under it.** One column for each gas or dissolved particle.
2. **Fill in the Initial row, in mol/L.** Given moles and a volume? Divide: moles ÷ litres. Not mentioned? Write 0.
3. **Find the column with two values. Work out its change.** Change = equilibrium − initial.
4. **Use the mole ratio to fill in the rest of the Change row.** Multiply by (coefficient you want ÷ coefficient you have). Reactants and products have opposite signs.
5. **Fill in the Equilibrium row.** Equilibrium = initial + change.
6. **Put the Equilibrium row into the equilibrium law expression.** Round only at the end. K_c has no units.

Worked example

2.00 mol of $N_2(g)$ and 6.00 mol of $H_2(g)$ are sealed in a 4.00 L container: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$. At equilibrium, $[NH_3(g)]$ = 0.200 mol/L. Find K_c.

Step 2
$[N_2(g)]$ = 2.00 mol ÷ 4.00 L = 0.500 mol/L. $[H_2(g)]$ = 6.00 mol ÷ 4.00 L = 1.50 mol/L. $NH_3(g)$ is not mentioned at the start, so it is 0.

Step 3
The $NH_3(g)$ column has two values: 0 and 0.200. Its change is +0.200 mol/L.

Step 4
$N_2(g)$: 0.200 × (1 ÷ 2) = 0.100, and it is a reactant, so −0.100. $H_2(g)$: 0.200 × (3 ÷ 2) = 0.300, so −0.300.

Step 5

	$N_2(g)$	$3H_2(g)$	$2NH_3(g)$
Initial	0.500	1.50	0
Change	−0.100	−0.300	+0.200
Equilibrium	0.400	1.20	0.200

Step 6
$$K_C = \frac{[NH_3(g)]^2}{[N_2(g)][H_2(g)]^3} = \frac{(0.200)^2}{(0.400)(1.20)^3} = 0.0579$$

Answer
K_C = 0.0579

The common mistake

Putting moles, or initial values, into the expression. Only **equilibrium concentrations in mol/L** go in. Also: giving every substance the same change. The changes follow the mole ratio.

Your turn

Work on paper. Then check your answers.

QUESTION 1 · EASY · NUMERICAL RESPONSE

0.600 mol/L of CO(g) and 0.600 mol/L of $Cl_2(g)$ are sealed in a container: $CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$. At equilibrium, $[COCl_2(g)]$ = 0.450 mol/L.

The equilibrium concentration of CO(g) is _____ mol/L. (Record your three-digit answer.)

Answer:

QUESTION 2 · MEDIUM · MULTIPLE CHOICE

For the system in question 1, the value of the equilibrium constant is

A. 3.00

B. 20.0

C. 0.0500

D. 1.25

QUESTION 3 · MEDIUM · NUMERICAL RESPONSE

1.00 mol of $PCl_5(g)$ is sealed in a 2.00 L flask and heated: $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$. At equilibrium the flask holds 0.300 mol of $Cl_2(g)$.

The value of the equilibrium constant, written as $0.0abc$, has the digits a, b and c equal to _____, _____ and _____. (Record all three digits.)

Answer: ☐

QUESTION 4 · MEDIUM · MULTIPLE CHOICE

$N_2O_4(g)$ is sealed in a flask at 0.400 mol/L: $N_2O_4(g) \rightleftharpoons 2NO_2(g)$. At equilibrium, 25.0% of the $N_2O_4(g)$ has reacted. The value of the equilibrium constant is

A. 0.667

B. 0.0333

C. 0.133

D. 7.50

QUESTION 5 · EXAM LEVEL · NUMERICAL RESPONSE

2.00 mol of NOCl(g) is sealed in a 2.00 L flask: $2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$. At equilibrium, $[Cl_2(g)] = 0.100$ mol/L.

The value of the equilibrium constant, in scientific notation, is $a.bc \times 10^{-d}$. The values of a, b, c and d are _____, _____, _____ and _____. (Record all four digits.)

Answer: ☐

CHALLENGE

Only $CH_3OH(g)$ is put into a sealed reactor, at 1.00 mol/L: $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$. At equilibrium, $[H_2(g)] = 0.400$ mol/L. Find K_C.

▼ **Hint**

The reactor starts with product only. So which side goes down, and which side goes up?

▼ **Check your answers for Card 5**

Question 1: 0.150. $COCl_2(g)$ went from 0 to 0.450, a change of +0.450 mol/L. The ratio of CO(g) to $COCl_2(g)$ is 1 to 1, so CO(g) changes by −0.450 mol/L. 0.600 − 0.450 = 0.150 mol/L.

Question 2: B. At equilibrium, $[CO(g)] = [Cl_2(g)] = 0.150$ mol/L and $[COCl_2(g)] = 0.450$ mol/L. $K_C = \frac{[COCl_2(g)]}{[CO(g)][Cl_2(g)]} = \frac{0.450}{(0.150)(0.150)} = 20.0$. The value 1.25 comes from using the initial concentrations, which is wrong.

Question 3: 643. Change to mol/L first. $[PCl_5(g)]$ at the start = 1.00 ÷ 2.00 = 0.500 mol/L. $[Cl_2(g)]$ at equilibrium = 0.300 ÷ 2.00 = 0.150 mol/L, a change of +0.150. So $[PCl_3(g)] = 0.150$ mol/L and $[PCl_5(g)] = 0.500 - 0.150 = 0.350$ mol/L. $K_C = \frac{(0.150)(0.150)}{0.350} = 0.0643$. Record 643.

Question 4: C. 25.0% of 0.400 is 0.100, so $N_2O_4(g)$ changes by −0.100 mol/L and ends at 0.300 mol/L. $NO_2(g)$ changes by twice as much: +0.200 mol/L. $K_C = \frac{[NO_2(g)]^2}{[N_2O_4(g)]} = \frac{(0.200)^2}{0.300} = 0.133$.

Question 5: 6253. [NOCl(g)] at the start = 2.00 ÷ 2.00 = 1.00 mol/L. $Cl_2(g)$ changes by +0.100. NO(g) changes by twice as much, +0.200. NOCl(g) changes by −0.200, to 0.800 mol/L. $K_C = \frac{[NO(g)]^2[Cl_2(g)]}{[NOCl(g)]^2} = \frac{(0.200)^2(0.100)}{(0.800)^2} = 0.00625 = 6.25 \times 10^{-3}$. Record 6253.

Challenge. The reaction runs in reverse to reach equilibrium. $H_2(g)$ goes from 0 to 0.400: +0.400. CO(g) changes by half as much: +0.200. $CH_3OH(g)$ changes by −0.200, to 0.800 mol/L. $K_C = \frac{[CH_3OH(g)]}{[CO(g)][H_2(g)]^2} = \frac{0.800}{(0.200)(0.400)^2} = 25.0$. The expression is still written for the equation as given: products on top.

Card 5 check

Answer these three on paper and show Mr F. They tell you both if you are ready to move on.

1. 1.00 mol/L of $H_2(g)$ and 1.00 mol/L of $F_2(g)$ react: $H_2(g) + F_2(g) \rightleftharpoons 2HF(g)$. At equilibrium, $[HF(g)] = 1.60$ mol/L. What is $[H_2(g)]$ at equilibrium?
2. Find K_C for the system in question 1.
3. Which row of an ICE table follows the mole ratio?

Need more? Read the Big ideas page again: Idea 5 · Idea 2. Stuck on a word? Look in Words to know.

Card 6: Find an equilibrium concentration from K_c

I can use K_c to find a concentration at equilibrium, and an ICE table to find a concentration at the start.

How to spot it on the diploma

- You are given K_c and all the equilibrium concentrations but one.
- "The equilibrium concentration of … is _____ mol/L."
- You are given K_c and one equilibrium concentration, and asked for a concentration **at the start**.

The steps

1. **Write the equilibrium law expression.** Products on top, reactants on the bottom, coefficients as powers.
2. **Put in K_c and every equilibrium concentration you know.** If two products form from one reactant in a 1 to 1 ratio, and neither was there at the start, they are equal.
3. **Solve for the one that is missing.** If it is squared, take the square root at the end.
4. **Asked for an initial concentration? Use an ICE table.** Initial = equilibrium − change. For a reactant the change is negative, so the initial value is larger.
5. **Check the answer.** Put all the equilibrium values back into the expression. You should get K_c.

Worked example

At one temperature, $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ has $K_c = 14.5$. At equilibrium, $[CO(g)] = 0.250$ mol/L and $[H_2(g)] = 0.400$ mol/L. Find $[CH_3OH(g)]$ at equilibrium.

> **Step 1**
> $K_c = \dfrac{[CH_3OH(g)]}{[CO(g)][H_2(g)]^2}$
>
> **Step 2**
> $14.5 = \dfrac{[CH_3OH(g)]}{(0.250)(0.400)^2}$
>
> **Step 3**
> $[CH_3OH(g)] = 14.5 \times 0.250 \times (0.400)^2 = 0.580$ mol/L
>
> **Step 5**
> Check: $\dfrac{0.580}{(0.250)(0.400)^2} = 14.5$. It matches.
>
> **Answer**
> $[CH_3OH(g)] = 0.580$ mol/L

The common mistake

Stopping at the equilibrium concentration when the question asks for the **initial** one. Read the last line of the question again. Also: forgetting the square root when the unknown is squared.

Your turn

Work on paper. Then check your answers.

QUESTION 1 · EASY · MULTIPLE CHOICE

At one temperature, $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ has $K_C = 0.0420$. At equilibrium, $[PCl_3(g)] = 0.210$ mol/L and $[Cl_2(g)] = 0.210$ mol/L. The equilibrium concentration of $PCl_5(g)$ is

A. 0.00185 mol/L

B. 0.952 mol/L

C. 1.05 mol/L

D. 5.00 mol/L

QUESTION 2 · MEDIUM · NUMERICAL RESPONSE

At one temperature, $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ has $K_C = 0.500$. At equilibrium, $[N_2(g)] = 0.800$ mol/L and $[H_2(g)] = 0.500$ mol/L.

The equilibrium concentration of $NH_3(g)$ is _____ mol/L. (Record your three-digit answer.)

Answer: [ ]

QUESTION 3 · MEDIUM · MULTIPLE CHOICE

At one temperature, $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ has $K_C = 0.00460$. At equilibrium, $[NO_2(g)] = 0.0300$ mol/L. The equilibrium concentration of $N_2O_4(g)$ is

A. 0.196 mol/L

B. 6.52 mol/L

C. 0.153 mol/L

D. 13.0 mol/L

QUESTION 4 · MEDIUM · NUMERICAL RESPONSE

Only HBr(g) is put into a sealed flask and heated: $2HBr(g) \rightleftharpoons H_2(g) + Br_2(g)$. At this temperature, K_C = 0.0100. At equilibrium, $[H_2(g)]$ = 0.0500 mol/L.

The equilibrium concentration of HBr(g) is _____ mol/L. (Record your three-digit answer.)

Answer: ☐

QUESTION 5 · EXAM LEVEL · NUMERICAL RESPONSE

Only $PCl_5(g)$ is put into a sealed flask and heated: $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$. At this temperature, K_C = 0.0500. At equilibrium, $[Cl_2(g)]$ = 0.150 mol/L.

The **initial** concentration of $PCl_5(g)$ was _____ mol/L. (Record your three-digit answer.)

Answer: ☐

CHALLENGE

0.800 mol/L of $NO_2(g)$ and 0.800 mol/L of $SO_2(g)$ are sealed in a flask: $NO_2(g) + SO_2(g) \rightleftharpoons NO(g) + SO_3(g)$. At this temperature, K_C = 9.00. Find $[NO(g)]$ at equilibrium. Let the change be *x*.

▼ **Hint**

Both reactants end at 0.800 − x. Both products end at x. The expression is then a square on top and a square on the bottom. Take the square root of both sides.

▼ **Check your answers for Card 6**

Question 1: C. $K_C = \frac{[PCl_3(g)][Cl_2(g)]}{[PCl_5(g)]}$, so $[PCl_5(g)] = \frac{(0.210)(0.210)}{0.0420}$ = 1.05 mol/L.

Question 2: 0.224. $K_C = \frac{[NH_3(g)]^2}{[N_2(g)][H_2(g)]^3}$, so $[NH_3(g)]^2 = 0.500 \times 0.800 \times (0.500)^3 = 0.0500$. Take the square root: $[NH_3(g)]$ = 0.224 mol/L.

Question 3: A. $K_C = \frac{[NO_2(g)]^2}{[N_2O_4(g)]}$, so $[N_2O_4(g)] = \frac{(0.0300)^2}{0.00460}$ = 0.196 mol/L. $NO_2(g)$ must be squared.

Question 4: 0.500. $H_2(g)$ and $Br_2(g)$ form in a 1 to 1 ratio from nothing, so $[Br_2(g)]$ = 0.0500 mol/L too. $K_C = \frac{[H_2(g)][Br_2(g)]}{[HBr(g)]^2}$, so $[HBr(g)]^2 = \frac{(0.0500)(0.0500)}{0.0100}$ = 0.250. Take the square root: $[HBr(g)]$ = 0.500 mol/L.

Question 5: 0.600. $[PCl_3(g)] = [Cl_2(g)] = 0.150$ mol/L. $[PCl_5(g)]$ at equilibrium $= \frac{(0.150)(0.150)}{0.0500} = 0.450$ mol/L. Now the ICE table: $Cl_2(g)$ changed by +0.150, so $PCl_5(g)$ changed by −0.150. Initial = equilibrium − change = 0.450 + 0.150 = 0.600 mol/L.

Challenge. $K_C = \frac{x^2}{(0.800 - x)^2} = 9.00$. Take the square root of both sides: $\frac{x}{0.800 - x} = 3.00$. So $x = 2.40 - 3.00x$, then $4.00x = 2.40$, and $x = 0.600$. $[NO(g)] = 0.600$ mol/L. Check: $(0.600)^2 \div (0.200)^2 = 9.00$. On the exam, you never need the quadratic formula.

Card 6 check

Answer these three on paper and show Mr F. They tell you both if you are ready to move on.

1. At one temperature, $2NO_2(g) \rightleftharpoons N_2O_4(g)$ has $K_C = 8.00$. At equilibrium, $[NO_2(g)] = 0.250$ mol/L. Find $[N_2O_4(g)]$.
2. In question 1, only $NO_2(g)$ was in the flask at the start. What was its initial concentration?
3. What do you do last, when the unknown concentration is squared?

Need more? Read the Big ideas page again: Idea 5 · Idea 2. Stuck on a word? Look in Words to know.