

Gas-Phase and Heterogeneous Equilibria

How do you write equilibrium constants with partial pressures, and what happens when solids or liquids take part?

●●○ Intermediate

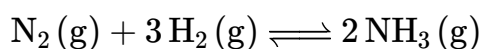
Equilibrium

Last reviewed 6 October 2026

Before you start: it helps to understand [Chemical Equilibrium and \$K_c\$](#) and [Gas Mixtures and Gas Stoichiometry](#).

What is it?

For reactions of gases, it is often easier to measure **partial pressures** than concentrations. The equilibrium constant written with partial pressures is K_p . For



$$K_p = \frac{(P_{\text{NH}_3})^2}{P_{\text{N}_2} (P_{\text{H}_2})^3}$$

It has exactly the same form as K_c , with each partial pressure (in atm) in place of a concentration.

A **heterogeneous** equilibrium involves more than one phase. **Pure solids and pure liquids are left out of K** , because their “concentration” does not change as they are used up. For the decomposition of limestone:



$$K_p = P_{\text{CO}_2}$$

💡 KEY IDEA

K_c and K_p describe the same equilibrium in different units. Because $P = \frac{n}{V}RT = cRT$ for each gas, they are linked by

$$K_p = K_c (RT)^{\Delta n}$$

where Δn = moles of gaseous products – moles of gaseous reactants. When $\Delta n = 0$, $K_p = K_c$.

Why does it matter?

- **Industry.** Ammonia, sulfuric acid and methanol are made by gas-phase equilibria; engineers use K_p to choose pressures and temperatures.
- **The atmosphere.** Reactions such as $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$ (a brown gas in smog) are gas equilibria.
- **Solids and gases together.** Limestone kilns, rusting and the equilibrium vapour pressure of water are all heterogeneous equilibria.

How does it work?

1. Writing K_p

Products over reactants, each partial pressure raised to its coefficient; leave out solids and liquids.

2. Converting between K_c and K_p

1. Find Δn from the **gas** coefficients only.
2. Use $R = 0.08206 \text{ L}\cdot\text{atm}/(\text{mol}\cdot\text{K})$ and T in kelvin.
3. $K_p = K_c(RT)^{\Delta n}$.

3. ICE tables with pressures

Pressures behave like concentrations: set up Initial, Change and Equilibrium rows in **atm**, substitute into K_p and solve.

THINK OF IT LIKE THIS

K_c and K_p are like the same price written in two currencies. The exchange rate is $(RT)^{\Delta n}$. If the reaction has the same number of gas molecules on both sides, there is nothing to convert: the price is identical in both.

MORE PRECISELY

Strictly, equilibrium constants use dimensionless activities: each partial pressure is divided by the standard pressure (1 bar, or 1 atm in older tables), which is why K has no units. Values of K_p therefore depend slightly on whether pressures are in bar or atm. The K in $\Delta G^\circ = -RT \ln K$ is K_p for gas reactions.

Visualise it

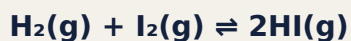
K_p, K_c and Δn

$K_p = K_c(RT)^{\Delta n}$ · Δn counts gas moles only



$$\Delta n = 2 - 4 = -2$$

$K_p = K_c(RT)^{-2}$: **K_p is smaller than K_c**



$$\Delta n = 2 - 2 = 0$$

K_p = K_c



$$\Delta n = 1 - 0 = +1 \text{ (solids not counted)}$$

K_p = P(CO₂) · solids left out of K

Δn counts gas molecules only; solids and liquids are left out of K.

Worked example

WORKED EXAMPLE: K_p from partial pressures

Question: At 25 °C, an equilibrium mixture contains N₂O₄ at 0.70 atm and NO₂ at 0.32 atm. Calculate K_p for N₂O₄(g) ⇌ 2 NO₂(g).

$$\begin{aligned} K_p &= \frac{(P_{\text{NO}_2})^2}{P_{\text{N}_2\text{O}_4}} = \frac{(0.32)^2}{0.70} \\ &= 0.15 \end{aligned}$$

✎ **WORKED EXAMPLE:** From K_c to K_p

Question: For $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightleftharpoons 2 \text{NH}_3(\text{g})$, $K_c = 0.50$ at 400°C . Find K_p .

Step 1 $\Delta n = 2 - (1 + 3) = -2$; $T = 400 + 273.15 = 673.15 \text{ K}$.

Step 2 RT :

$$\begin{aligned} RT &= 0.08206 \frac{\text{L atm}}{\text{mol K}} \\ &\times 673.15 \text{ K} \\ &= 55.24 \text{ L atm/mol} \end{aligned}$$

Step 3 Then, using the number 55.24 (K values are written without units):

$$\begin{aligned} K_p &= 0.50 \times (55.24)^{-2} \\ &= 1.6 \times 10^{-4} \end{aligned}$$

✎ **WORKED EXAMPLE:** A heterogeneous equilibrium

Question: Write K_c and K_p for $\text{C}(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + \text{H}_2(\text{g})$.

Carbon is a pure solid, so it is left out:

$$\begin{aligned} K_c &= \frac{[\text{CO}][\text{H}_2]}{[\text{H}_2\text{O}]} \\ K_p &= \frac{P_{\text{CO}} P_{\text{H}_2}}{P_{\text{H}_2\text{O}}} \end{aligned}$$

 WORKED EXAMPLE: An ICE table with pressures

Question: $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g})$ has $K_p = 1.05$ at a certain temperature. Pure PCl_5 at 1.00 atm is allowed to reach equilibrium. Find the equilibrium partial pressures.

Step 1 ICE (atm): $\text{PCl}_5: 1.00 - x; \text{PCl}_3: x; \text{Cl}_2: x$.

Step 2 Substitute:

$$\frac{x^2}{1.00 - x} = 1.05$$
$$x^2 + 1.05x - 1.05 = 0$$

Step 3 Quadratic formula, positive root, with $a = 1, b = 1.05, c = -1.05$:

$$x = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$
$$= \frac{-1.05 + \sqrt{5.3025}}{2}$$
$$= 0.626$$

Step 4 $P_{\text{PCl}_3} = P_{\text{Cl}_2} = 0.626 \text{ atm}$ and $P_{\text{PCl}_5} = 1.00 - 0.626 = 0.374 \text{ atm}$. Check:
 $\frac{0.626^2}{0.374} = 1.05 \checkmark$.

Common mistake

 COMMON MISTAKE: Including solids or liquids

In $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$, $K_p = P_{\text{CO}_2}$ only. Writing $\frac{P_{\text{CaO}}P_{\text{CO}_2}}{P_{\text{CaCO}_3}}$ is wrong: solids have no partial pressure.

 COMMON MISTAKE: Counting all moles in Δn

Δn counts **gas** moles only. For $\text{C}(\text{s}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + \text{H}_2(\text{g})$, $\Delta n = 2 - 1 = +1$, not $2 - 2$.

 COMMON MISTAKE: Using the wrong R or temperature

With pressures in atm, use $R = 0.08206 \text{ L}\cdot\text{atm}/(\text{mol}\cdot\text{K})$, not 8.314, and always convert $^\circ\text{C}$ to K.

NOTATION NOTE

- P_A means the partial pressure of A at equilibrium (in atm here).
- K_c uses mol/L; K_p uses partial pressures. Both are quoted without units.

Remember this

REMEMBER THIS

- K_p : same form as K_c , with partial pressures.
- $K_p = K_c(RT)^{\Delta n}$; Δn = gas moles (products – reactants); $R = 0.08206$; T in K.
- Leave pure solids and liquids out of K .
- ICE tables work with pressures just as with concentrations.

References

1. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

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