

Phase Diagrams

How can you tell which state a substance is in at any temperature and pressure?

●●○ Intermediate

States of Matter & Gases

Last reviewed 5 October 2026

Before you start: it helps to understand [Phase Changes and Heating Curves](#).

What is it?

A **phase diagram** is a map that shows which state (phase) of a substance is stable at each combination of **temperature** (horizontal axis) and **pressure** (vertical axis).

- The three **areas** are the regions where the substance is solid, liquid or gas.
- The **lines** between them show the conditions where two phases exist together in equilibrium. Crossing a line means a phase change: the solid–liquid line gives the melting point at each pressure, the liquid–gas line the boiling point, and the solid–gas line the sublimation point.
- At the **triple point**, all three phases coexist.
- The liquid–gas line ends at the **critical point**. Above it, liquid and gas can no longer be told apart: the substance is a **supercritical fluid**.

KEY IDEA

To read a phase diagram, find the point for the given temperature and pressure and see which region it lies in. The **normal** melting and boiling points are where the horizontal line at **1 atm** crosses the solid–liquid and liquid–gas lines.

Why does it matter?

- **Dry ice.** Solid CO_2 turns straight into gas at room pressure, with no liquid: the phase diagram explains why.
- **Freeze-drying and decaffeination.** Freeze-drying works below water's triple point, where ice sublimates. Supercritical CO_2 is used to remove caffeine from coffee.
- **Weather and planets.** Phase diagrams explain why liquid water cannot exist on the surface of Mars, where the pressure is below water's triple point.

How does it work?

1. Reading the diagram

For a point at a given temperature and pressure:

- **left** (low temperature) and **high pressure**: solid;
- **middle**: liquid;
- **right** (high temperature) and **low pressure**: gas.

Moving **horizontally** (changing temperature at constant pressure) traces a heating or cooling curve. Moving **vertically** (changing pressure at constant temperature) shows what compression or expansion does.

2. Water: an unusual slope

For almost every substance the solid–liquid line slopes **to the right** (more pressure raises the melting point), because the solid is denser than the liquid. **Water's line slopes to the left**: ice is **less** dense than liquid water, so squeezing ice favours the liquid and **lowers** the melting point slightly.

	Water	Carbon dioxide
Triple point	0.01 °C, 0.00604 atm	−56.6 °C, 5.11 atm
Critical point	374 °C, 218 atm	31.0 °C, 72.8 atm
At 1 atm	melts at 0 °C, boils at 100 °C	sublimes at −78.5 °C
Solid–liquid line	slopes left	slopes right

3. Carbon dioxide: no liquid at 1 atm

The triple-point pressure of CO₂ (5.11 atm) is **above** 1 atm. At atmospheric pressure the horizontal line misses the liquid region completely, so solid CO₂ goes straight to gas. Liquid CO₂ only exists above 5.11 atm, for example inside a fire extinguisher.

∞ THINK OF IT LIKE THIS

A phase diagram is like a map with three countries: Solid, Liquid and Gas. The borders are the lines, where two countries meet. The triple point is the one spot where all three borders meet. The critical point is where the border between Liquid and Gas simply fades away.

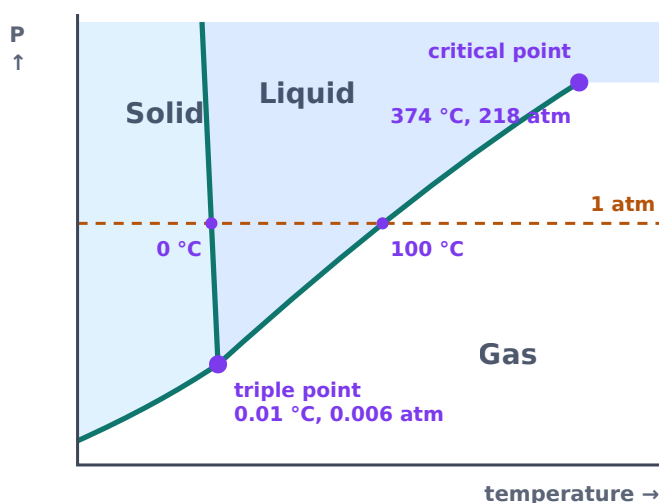
Q MORE PRECISELY

The slope of each line is given by the Clapeyron equation: it depends on the enthalpy and the volume change of the transition. Because ice has a larger volume than liquid water, the volume change on melting is negative and the slope is negative. The liquid–gas line is the vapour-pressure curve: each point gives the vapour pressure of the liquid at that temperature. Real phase diagrams of water are much more complicated at very high pressures, with many different forms of ice.

Visualise it

Phase diagram of water

Schematic: not to scale



Phase diagram of water (schematic, not to scale).

Worked example

WORKED EXAMPLE: Reading the CO₂ data

Question: In which state is carbon dioxide at (a) 1 atm and 25 °C (b) 60 atm and 0 °C (c) 100 atm and 40 °C?

Step 1 (a) Above its sublimation point at 1 atm (−78.5 °C): **gas**.

Step 2 (b) Above the triple-point pressure, and 60 atm is above the vapour pressure of liquid CO₂ at 0 °C (about 34 atm): **liquid**.

Step 3 (c) Above both 31.0 °C and 72.8 atm, the critical point: **supercritical fluid**.

 WORKED EXAMPLE: Why dry ice sublimates

Question: Explain why solid CO₂ at 1 atm turns directly into gas, while ice melts.

At 1 atm, CO₂ is below its triple-point pressure (5.11 atm), so the 1 atm line passes from the solid region straight into the gas region: **sublimation**. For water, 1 atm is far above the triple-point pressure (0.00604 atm), so the 1 atm line crosses the liquid region: ice **melts**, then boils.

 WORKED EXAMPLE: Converting triple-point pressures

Question: Express the triple-point pressures of water (611.7 Pa) and CO₂ (5.11 atm) in kPa.

Step 1 Water:

$$611.7 \cancel{\text{Pa}} \times \frac{1 \text{ kPa}}{1000 \cancel{\text{Pa}}} \\ = 0.6117 \text{ kPa}$$

Step 2 CO₂:

$$5.11 \cancel{\text{ atm}} \times \frac{101.325 \text{ kPa}}{1 \cancel{\text{ atm}}} \\ = 518 \text{ kPa}$$

Step 3 CO₂'s triple point is about 850 times higher in pressure than water's.

 WORKED EXAMPLE: Pressure and ice

Question: Ice at -1 °C is squeezed very hard. Using water's phase diagram, what could happen?

Because water's solid-liquid line slopes to the **left**, a vertical move upwards (higher pressure) from a point just left of the line can cross into the **liquid** region. Enough pressure can melt ice slightly below 0 °C.

Common mistake

 COMMON MISTAKE: Swapping the axes

Phase diagrams almost always have **temperature on the x-axis** and **pressure on the y-axis**. Read the axis labels before deciding which way "higher" is.

 COMMON MISTAKE: Thinking the triple point is a normal melting point

The triple point is at one specific pressure (0.00604 atm for water), not at 1 atm. The normal melting point (0 °C) and the triple point (0.01 °C) are close for water, but they are different points.

 COMMON MISTAKE: Assuming every substance has a liquid at 1 atm

CO₂ has no liquid at 1 atm, because its triple point lies above 1 atm.

 NOTATION NOTE

- “Normal” melting and boiling points are measured at exactly 1 atm.
- The pressure axis is often drawn on a stretched or logarithmic scale, so diagrams are usually not to scale.

Remember this

 REMEMBER THIS

- Axes: temperature (x) and pressure (y); areas = single phases; lines = two phases in equilibrium.
- Triple point: all three phases coexist. Critical point: end of the liquid–gas line; beyond it, a supercritical fluid.
- Normal melting and boiling points lie on the 1 atm line.
- Water’s solid–liquid line slopes left because ice is less dense than liquid water.
- CO₂ sublimates at 1 atm because its triple-point pressure (5.11 atm) is above 1 atm.

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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