More Than Three States of Matter

Solid, liquid, gas – and the ones nobody told you about

Solid, liquid, gas. Three neat boxes, learned in primary school and never questioned. But the most common state of matter in the universe isn't on that list – and the boxes leak.

EXAM LINKS *AQA A-level Physics (7408): 3.6 Further mechanics and thermal physics – states of matter, internal energy, changes of state. Wider reading: plasma and low-temperature physics.*

Ask almost anyone how many states of matter there are and they'll say three: solid, liquid and gas. It's one of the very first things we learn about the physical world, and it feels as settled as "there are seven days in a week". It is also badly incomplete. There are more states than three, the boundaries between them are blurrier than you were told, and – remarkably – the state that makes up most of the visible universe is one you were never taught at all.

The fourth state: plasma

Heat a gas hot enough and something new happens. The atoms collide so violently that electrons are torn away from their nuclei, leaving a roiling mixture of free electrons and charged ions. This is **plasma**, and because it is full of moving charges it conducts electricity and responds to magnetic fields in ways an ordinary gas never could.

Plasma is not exotic – it is everywhere. The Sun and every other star is a ball of plasma. So is a bolt of lightning, the glow inside a neon sign, the flame of a candle at its hottest, and the shimmering aurora. In fact, because stars are plasma and stars make up almost all the visible matter in the cosmos, **plasma is by far the most common state of matter in the universe**. The "normal" three states you know are the local oddities, clinging to a cool little planet.

The boxes leak: when is a solid not a solid?

Even the familiar three don't behave. Glass looks and feels solid, but its atoms are jumbled with no regular repeating pattern, like a liquid frozen mid-flow – physicists call it an *amorphous solid* and argue happily about whether it counts as a true solid at all. Pitch (a tar-like substance) is so stiff it shatters if you hit it, yet it flows so slowly that a famous experiment started in 1927 has dripped only a handful of times. Meanwhile a *liquid crystal* – the stuff in the screen you may be reading this on – flows like a liquid but keeps its molecules lined up like a solid. The tidy categories are really the middle of a spectrum, not a set of sealed boxes.

Stranger still: near absolute zero

Go the other way – towards the coldest temperatures possible – and matter does things that sound made up. Cooled to within a whisker of **absolute zero** (–273.15°C, the coldest anything can ever be), certain gases collapse into a **Bose–Einstein condensate**, a state predicted by Einstein in 1924 but not made in a lab until 1995. In it, thousands of atoms stop behaving as individuals and merge into a single quantum entity, all doing exactly the same thing at once – matter behaving like one giant wave.

Nearby lies *superfluidity*: liquid helium, chilled enough, loses all friction and will creep up the walls of its container and flow out over the top, apparently defying gravity, because nothing resists its motion. These are not tricks. They are what matter genuinely does once the everyday rules run out.

So how many states are there?

> There is no tidy final number – and that's the point. Physicists count solid, liquid, gas and plasma as the everyday four, then add exotic states such as Bose–Einstein condensates, superfluids, supercritical fluids (where liquid and gas become indistinguishable) and more, with new ones still being discovered. "How many states of matter are there?" turns out to be less like "how many days in a week?" and more like "how many colours are there?" – the answer depends on how finely you choose to look. A question that felt closed in primary school is, in fact, wide open.

Why this matters

This is not trivia. Controlling plasma is the central challenge of nuclear fusion, humanity's best hope for near-limitless clean energy. Liquid crystals built the display industry. Superconductors – close cousins of these low-

temperature states – make MRI scanners and maglev trains possible. Every one of these technologies lives in the territory beyond "solid, liquid, gas". Learning that a simple, trusted classification was only ever the beginning is exactly the kind of thinking A-level Physics asks of you.

Terms explained

Plasma A state of matter, made of free electrons and ions, that forms when a gas becomes hot enough to lose electrons; it conducts electricity and responds to magnetic fields.

Ion An atom that has gained or lost one or more electrons, giving it an electric charge.

Amorphous solid A solid, such as glass, whose atoms have no regular repeating arrangement.

Absolute zero The lowest possible temperature (–273.15°C or 0 kelvin), at which particle motion is at its minimum.

Bose–Einstein condensate A state formed near absolute zero in which many atoms merge into a single quantum state and behave as one.

Superfluid A fluid with zero friction (viscosity) that can flow without losing energy and can creep up container walls.

Key points

- Solid, liquid and gas are not the whole story; plasma is a fourth everyday state.
- Plasma – stars, lightning, neon signs – is the most common state of matter in the visible universe.
- The familiar states form a spectrum: glass, pitch and liquid crystals sit awkwardly between the categories.
- Near absolute zero, matter forms exotic states such as Bose–Einstein condensates and superfluids.
- There is no single fixed number of states of matter – new ones are still being found.

Think about …

- A candle flame, a neon sign and the Sun are all given as examples of plasma. What do they have in common that an ordinary gas lacks?
- Glass is sometimes described as neither a true solid nor a true liquid. Suggest why physicists find it hard to classify.
- Plasma is the most common state in the universe but rare in everyday life on Earth. Suggest a reason for this difference.
- Why might controlling plasma be so much harder than controlling a normal gas? (Think about what plasma responds to that a gas does not.)