Inside the Sun – What's Happening? What's it like?

The sun is not a simple ball of hot gas. It is much more complex.

What is Inside the Sun?

Internal Structure

The structure of the Sun is divided into six distinct layers, organized into three **interior layers** and three **atmospheric layers**.

Because the Sun is a plasma, there are no solid surfaces. Instead, the layers change based on temperature, density, and how energy moves through them.

The Interior Layers of the Sun

The interior accounts for the vast majority of the Sun's mass and is where all its energy is generated and transported outward.

- **1. The Core:**
    - **Location:** The innermost 25% of the Sun's radius.
    - **Temperature:** approx 15,000,000 Kelvin.
    - **What happens here:** This is the Sun's powerhouse. Extreme gravitational pressure packs plasma to 13 times the density of lead, triggering the nuclear fusion of hydrogen into helium.
- **2. The Radiative Zone:**
    - **Location:** Extends from the core to about 70% of the way to the surface.
    - **Temperature:** Drops from 7,000,000 K to 2,000,000 K.
    - **What happens here:** Energy moves outward incredibly slowly as light particles (photons). The plasma is so densely packed that photons constantly crash into electrons and bounce in random directions, taking over 100,000 years to cross this single zone.
- **3. The Convective Zone:**
    - **Location:** The outer 30% of the Sun's interior.
    - **Temperature:** Drops to about 5,800 K at the top.
    - **What happens here:** The plasma becomes cooler and more opaque, trapping heat. The Sun switches from radiating light to mechanical boiling. Giant currents of hot plasma rise to the surface, cool down, and sink back down, transporting energy to the surface in just a few weeks.

The Atmospheric Layers Above the Sun

The atmosphere represents the outer, visible parts of the Sun that bleed directly into the vacuum of space.

- **4. The Photosphere - The Visible Surface:**
    - **Thickness:** approx 400 kilometres deep.
    - **Temperature:** approx 5,800 K (5,500°C).

  - **What happens here:** This is the "surface" we see from Earth. The plasma density drops enough for photons to finally break free and fly straight through space as sunlight. This layer is also home to cooler, magnetic dark spots called **sunspots**.

- **5. The Chromosphere:**
  - **Thickness:** approx 2,000 kilometres deep.
  - **Temperature:** Rises from 4,000 K to about 25,000 K.
  - **What happens here:** A thin, reddish-glowing layer of hydrogen gas. It acts as a turbulent transition zone where massive loops of plasma, known as **prominences**, shoot out from the surface into space.

- **6. The Corona - The Outer Atmosphere:**
  - **Location:** Extends millions of kilometres out into space.
  - **Temperature:** Blisters up to **1,000,000 K to 3,000,000 K**.
  - **What happens here:** A Wispy, halo-like outer atmosphere visible to the naked eye only during a total solar eclipse. Mysteriously, it is hundreds of times hotter than the Sun's surface, a paradox driven by intense magnetic field energy. The corona constantly streams particles out into the Solar System, creating the **solar wind**. This region is only really visible from Earth during a solar eclipse when the Moon blocks the extremely bright light of the sun's chromosphere.

Structure Summary

Layer	**Type**	**Temperature**	**State of Matter / Feature**
Core	Interior	15 Million K	Ultra-dense nuclear fusion furnace
Radiative Zone	Interior	7M K to 2M K	Photons trapped in a 100k-year "random walk"
Convective Zone	Interior	2M K to 5,800 K	Rolling, boiling currents of hot plasma
Photosphere	Atmosphere	5,800 K	The visible surface emitting yellow-white light
Chromosphere	Atmosphere	4,000 K to 25,000 K	Red-glowing layer featuring violent solar flares
Corona	Atmosphere	1M K to 3M K	Wispy, ultra-hot halo bleeding into the solar wind

How Dense is the Sun?

Density of the Sun's Core

The plasma at the centre of the Sun is approximately **13 times denser than the metal lead**.

The Numbers Break Down:

- **Density of Lead: 11.34 g/cm^3** at room temperature.
- **Density of the Solar Core: 150 g/cm^3** at the very centre.

To put this into perspective, a standard 1-litre carton of milk filled with plasma from the centre of the Sun would weigh **150 kilograms** on Earth. On Earth, lead weighs 11.34kg/litre. So, the plasma at the centre of the sun is 13x more dense than the metal lead.

The Quantum Difference: Why is a Plasma "Gas" Denser than a Heavy Metal?

It seems counterintuitive that a gas-like plasma could be vastly heavier than one of the densest everyday metals on Earth. The explanation lies in **atomic structure**:

- **Lead Atoms have "Elbow Room":** On Earth, the atoms in a solid piece of lead still retain their cloud of electrons. Because these negative electron clouds repel the electron clouds of neighbouring atoms, they cannot get too close to each other. This leaves a vast amount of empty space inside the metal's structure.

Solar Plasma is Fully Stripped of its Electrons Orbit Atomic Nuclei:

- At 15 million Kelvin, the heat is too extreme for electron clouds to exist in orbit around nuclei. The electrons are ripped completely away from the nuclei, turning the gas into a plasma of bare protons and free electrons. Because there are no bulky electron clouds to keep the particles apart, the crushing gravitational force of the Sun can pack the bare, tiny nuclei **exponentially closer together**.

If you took away the extreme heat and pressure holding it open, a handful of solar core plasma would instantly explode outward on Earth, as it requires the gravity of an entire star to keep it crushed into that dense of a state.

The Core of the Sun is a Battlefield

The centre of the Sun is a cosmic battlefield between two colossal, opposing physics phenomena: **the inward crush of gravity** and **the outward push of thermal and radiation pressure**.

When these two forces match each other perfectly, a star achieves a stable state known as **hydrostatic equilibrium**. This delicate balancing act acts as a giant cosmic thermostat, keeping the Sun from either expanding into space or collapsing entirely in on itself.

Fusion in the Core of the Sun

1. The Inward Force: Gravitational Compression

The Sun is unimaginably massive, containing about **99.8% of all the matter in our entire Solar System**.

- **The Accumulating Weight:** Every single layer of gas in the Sun pulls inward toward the exact centre. The deeper you go, the more weight sits above it.
- **The Crushing Core:** At the very centre, this accumulated weight generates an inward force resulting in a pressure of **250 billion atmospheres**.
- **Stripping Atoms Naked:** This extreme gravitational pressure forces particles into a super-tight space, stripping the electrons away from the protons and crushing them into a soup of raw plasma.

2. The Outward Force: Kinetic and Radiation Pressure

If gravity were the only force at play, the Sun would instantly collapse into a tiny, ultra-dense ball. However, compressing a gas causes a dramatic reaction based on the rules of thermodynamics:

- **Vastly Increased Particle Speeds:** As gravity crams the protons and electrons together, they are forced to move faster and faster. This extreme kinetic motion registers macroscopically as a blistering temperature of **15 million Kelvin.**
- **The Ignition of Nuclear Fusion:** Because the protons are moving at speeds of roughly 609,000 m/s, they crash into one another with enough energy to occasionally overcome their natural electrical repulsion and stick together. This process—nuclear fusion—converts hydrogen into helium.
- **Two Types of Outward Push:** The fusion process releases massive amounts of energy, fuelling two separate outward forces:
    1. **Thermal Pressure:** The hyper-fast protons and electrons are constantly colliding and ricocheting off one another, creating a kinetic "push" that forces the plasma to expand outward.
    2. **Radiation Pressure:** The fusion process creates a tidal wave of highly energetic photons (light particles). As these photons struggle to escape the core, they physically bump into the electrons and protons, exerting a literal, outward mechanical pressure against gravity.

3. The Natural Thermostat (Self-Regulation)

What makes the Sun so stable is that this relationship is **entirely self-regulating** and keeps the sun in a continuous stable fusion process:

Gravity Crushes Inward ——> Increases Core Density & Temp ——> Accelerates Fusion Rate

Core Cools & Contracts <—— Decreases Fusion Rate <—— Expands & Cools Core (Outward Pressure)

- **If Gravity Starts to Win:** The core compresses further. This packs the protons closer together and forces them to move faster, which causes the fusion rate to skyrocket. The sudden burst of extra energy increases the outward pressure, pushing gravity back.

- **If Fusion Starts to Win:** The massive outward pressure expands the core. Expansion causes the plasma to cool down and the particles to spread apart. Because the protons are now moving slower and hitting each other less often, the fusion rate drops, allowing gravity to pull it back to size.

Because of this beautifully balanced feedback loop, our Sun has maintained a rock-solid, steady size for nearly **4.6 billion years**.

Would you like to explore what happens when a star finally **runs out of hydrogen fuel** and this balance fails, or look closer at how **photons** transport this energy out of the core?

How Fast Do Particles Travel in the Centre of the Sun?

At the centre of the Sun, the matter is not in a normal molecular gas state. Instead, it is a **fully ionized plasma**. Because the extreme heat strips electrons away from atomic nuclei, the individual particles (free electrons and bare protons) act exactly like independent gas particles in an ideal gas.

When we measure the temperature of matter – whether a solid, liquid, gas, or plasma – we are actually determining how fast the atoms (or sub-atomic components) are moving or vibrating. Heat is a measure of how fast these components are moving. At the absolute zero temperature of exactly **0 Kelvin** (which corresponds to **-273.15°C**) the motion or vibration of components is zero. They do not vibrate or move. However, as their temperature increase, the speed or movement, or vibration, increases exponentially.

There is a mathematical formula that can estimate the speed at which particles travel in the centre of the sun.

1. Adjusting the Formula for Single Particles

Instead of using the macroscopic gas constant (R) and molar mass (M), physicists use **Boltzmann's constant (k_B)** and the actual **mass of the individual subatomic particle (m)** in kilograms:

$$v_{\mathrm{rms}} = \sqrt{\frac{3k_BT}{m}}$$

- **k_B (Boltzmann's Constant):** 1.3806 \times 10^-23 J/K
- **T (Core Temperature of the Sun):** Approximately **15,000,000 K** (15 million Kelvin)
- **m (Particle Mass):** The mass of the electron, proton, or neutron in kilogram.

2. Calculated Speeds in the Solar Core

Because all particles in the core share the exact same temperature (15,000,000 K), they all possess the exact same average thermal kinetic energy. However, because their masses differ wildly, **lighter particles move vastly faster than heavier ones**.

Using the formula, the speeds break down as follows:

Particle	Mass (m)	Calculated v_rms Speed	Comparison
Electron	9.109 x 10^-31 kg	approx 26,115,804 m/s (or 26,115 km/s)	approx 8.7% the speed of light
Proton	1.673 x 10^-27 kg	approx 609,465 m/s (or 609.4 km/s)	approx 0.2% the speed of light

By comparison, an oxygen molecule at 1 atmosphere and 25°C will travel at a speed of approximately **482 meters per second,** which is about **1,735 km/h**.

The oxygen molecule in air moves incredibly fast—well over the speed of sound in air, which is about 346 m/s at that same temperature. However, nothing like the particle speeds at the centre of the sun.

3. Caveat: The Relativity Factor

While the calculation is highly accurate for the protons and neutrons, it starts to slightly lose accuracy for the **electrons**.

Because electrons are so exceptionally light, the extreme heat forces them to travel at nearly 9% of the speed of light. At these velocities, **special relativity** kicks in. To get a perfect measurement for electrons, physicists must slightly adjust this classical formula to account for relativistic mass increases and time dilation.

4. The "Pinball" Catch

Even though an individual oxygen molecule is moving at bullet-like speeds, it cannot travel very far in a straight line at 1 atmosphere of pressure. Because the air is crowded with other molecules, it constantly collides with them—roughly **7 billion times every second**!

Because of these non-stop collisions, it moves in a chaotic, zig-zag path called a "random walk." This is why it takes a few seconds for a scent (like perfume) to drift across a room, even though the individual molecules are moving at supersonic speeds.

Each particle type experiences an entirely different collision rate based on its size, speed, and charge.

1. Protons (Hydrogen Nuclei)

A proton in the core of the sun experiences roughly **10^12 to 10^13 collisions per second** (1 to 10 trillion collisions).

- **The Nature of the Collision:** Because protons are positively charged, they don't actually physically "smack" into each other like billiard balls. Instead, their electromagnetic fields violently repel one another, deflecting their paths in what physicists call "Coulomb scattering".
- **The Fusion Miracle:** Even though a single proton collides trillions of times every second, the electrical repulsion is so strong that almost every single collision is a simple deflection. A proton has to collide about **10^25 to 10^2} times** before the conditions are just right for it to quantum-tunnel past the

electrical barrier and fuse. Because of these very small odds, it takes an average proton **9 to 10 billion years** to successfully undergo nuclear fusion.

2. Electrons

An electron in the solar core experiences an even higher collision rate, roughly **10^14 to 10^15 collisions per second** (100 to 1,000 trillion collisions per second).

- **Why so high?** As calculated previously, electrons move over 40 times faster than protons because they are so light. Because they are zipping through the crowded core at nearly 9% the speed of light, they cover more distance per second, drastically increasing their chances of running into other electrons and protons.

3. Neutrons

Free neutrons are rare in the Sun, but when they are briefly created during fusion steps, they experience a significantly lower collision rate—roughly **10^8 to 10^9 collisions per second** (hundreds of millions to a billion collisions per second).

- **Why so low?** Neutrons have **zero electrical charge**. They completely ignore the electromagnetic fields of the protons and electrons surrounding them. A neutron will fly completely straight, completely unaffected, until it achieves a direct, literal physical hit on an atomic nucleus via the strong nuclear force. Because nuclei are exceptionally tiny targets, the neutron's "mean free path" (distance between collisions) is much longer, resulting in fewer collisions per second.

Summary Table

Particle	**Average Speed**	**Collision Rate (Per Second)**	**Collision Mechanism**
Electron	approx 26,115,000 m/s (or 26,115km/s)	**approx 10^14 - 10^15** (1 Quadrillion per second)	Electromagnetic deflection
Proton	approx 609,000 m/s (or 609km/s)	**approx 10^12 - 10^13** (1 Trillion per second)	Electromagnetic deflection
Neutron	approx 609,000 m/s (or 609km/s)	**approx 10^8 - 10^9** (1 Billion per second)	Direct nuclear impact

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How Does Light and Heat Escape the Sun?

The Random Walk: How Photons Escape the Sun

A photon (a particle of light) created by nuclear fusion at the centre of the Sun takes roughly **100,000 to 200,000 years** to travel from the core to the surface. Yet, once it breaks free into open space, it covers the 150-million-kilometre distance to Earth in just **8 minutes and 20 seconds**.

This extreme delay inside the Sun is caused by two distinctly different zones:

- The Core: nuclear fusion
- The **Radiative Zone**: a light photo experiences a pinball journey taking about 100,000 years to move through and up to the next zone.
- The **Convective Zone**: a region of huge "boiling" blobs of gas that move upward through the zone due to their heat and lighter density. A journey taking about 10 days.
- Open Space: where photos can travel through space at the speed of light, reaching Earth in about 9 minutes.

Zone A: The Radiative Zone (The Ultimate Pinball Machine)

Directly surrounding the core is the radiative zone, which makes up about 70% of the Sun's radius.

- **Packed Like a Wall:** Even though the plasma here is a gas, it is packed so incredibly dense that a photon cannot travel more than a fraction of a millimetre (often just a few micrometres) before physically hitting a free electron.

- **The Chaotic Journey:** When a photon hits an electron, it is absorbed and immediately re-emitted in a completely random new direction—sometimes even right back toward the core! This chaotic, zig-zag path is called a **"random walk."**

- **Cooling Down:** As the photon undergoes trillions of these collisions over millennia, it constantly loses energy. It starts its journey as a highly lethal, high-energy **Gamma-ray**, but by the time it reaches the top of this zone, it has cooled down into lower-energy **X-rays** and **Ultraviolet light**.

Zone B: The Convective Zone (The Plasma Elevator)

In the outer 30% of the Sun, the temperature drops enough that the plasma becomes more opaque, trapping heat like a heavy blanket.

- **Boiling Motion:** Because the radiative pinball method becomes too slow to move the massive amount of trapped heat, the Sun switches to a mechanical cooling method: **convection**.

- **The 10-Day Ride:** Huge pockets of hot plasma at the bottom of this zone absorb the energy, become buoyant, and violently boil upward toward the surface—like a giant cosmic pot of boiling water. The photons ride inside these massive boiling bubbles, racing through this final layer in just **10 days**.

Freedom: Entering Open Space

When the boiling plasma reaches the Sun's surface (the **photosphere**), the density drops drastically. Suddenly, there are no longer enough electrons blocking the path.

- **The Final Release:** The photons are released all at once as visible light, infrared (heat), and ultraviolet rays.
- **The Straight Shot:** Because open space is an almost perfect vacuum with nearly zero particles to collide with, the photons stop their chaotic zig-zagging. They instantly accelerate to the cosmic speed limit—the speed of light (299,792 km/s)—and fly completely straight through the universe forever, unless they happen to strike an object like Earth.

Would you like to explore **what the White Dwarf remnants of our Sun will look like** in the deep future, or would you prefer to look at the **different layers of the Sun's atmosphere** (like the Corona) that light passes through on its way out?

What Happens When Fusion Stops?

When the Fuel Runs Out: The Collapse of the Balance

When the Sun's core runs out of hydrogen fuel in about **5 billion years**, the natural thermostat fails, and the star undergoes a dramatic transformation.

- **The Inward Collapse:** Without hydrogen fusion, the outward thermal and radiation pressure drops significantly. Gravity instantly wins the battle and begins to crush the core inward.
- **The Helium Core Ignites:** As the core compresses, it heats up to extreme temperatures (over 100 million Kelvin). This intense heat causes the core to become dense enough to fuse helium into carbon and oxygen.
- **The Red Giant Phase:** While the core collapses and heats up, a shell of remaining hydrogen just outside the core ignites. This sudden, massive burst of energy creates an overwhelming outward pressure that blows the outer layers of the Sun far out into space. The Sun will swell into a **Red Giant**, expanding so large that it will swallow Mercury, Venus, and likely Earth.
- **The Final Quiet End:** Eventually, the Sun will run out of helium too. It isn't massive enough to create the pressure needed to fuse carbon, so fusion stops completely. The outer layers will drift off into space as a beautiful glowing cloud (a planetary nebula), leaving behind only the dead, ultra-dense, cooling core—a **White Dwarf** about the size of Earth.

But, no need to worry about the end of the Sun. We can expect our planet Earth to be bathed by beautiful life-giving light and heat from the sun for billions of years into the future. Thank you, Sun.