



ANTIPARTICLES: SCIENCE & TECHNOLOGY

NEWS: Antimatter idea offers scientists clue to cracking cosmic mystery

WHAT'S IN THE NEWS?

Antiparticles, theorized in 1928, reveal quantum symmetry but are scarce, with matter dominating due to early universe asymmetry. Recent research on meson decays partially explains this imbalance, aligning with the Sakharov conditions for matter's survival.

Antiparticles and the Matter-Antimatter Asymmetry

Introduction to Antiparticles

- **Definition and Origin:**
 - Antiparticles are counterparts to particles, possessing the same mass but opposite charge.
 - The concept was theorized by **Paul Dirac in 1928** and first observed by **Carl Anderson in 1932**.
 - **Example:** The **antielectron (positron)** is the antiparticle of the electron, carrying a positive charge.
- **Quantum Mechanical Significance:**
 - Antiparticles emerge from the principles of **quantum mechanics** and **special relativity**.
 - They exhibit behaviors akin to traveling **backward in time** within quantum frameworks.

Scarcity of Antimatter in the Universe

- **Observable Universe Composition:**
 - While antiparticles are detectable in **cosmic rays** and even produced by **human bodies**, **antimatter remains scarce**.
 - The **universe** is predominantly composed of **matter**, leading to the formation of **galaxies, stars, and planets**.
- **Early Universe Asymmetry:**
 - Post-Big Bang, there was a **slight asymmetry**: for every **1.7 billion proton-antiproton pairs**, there was **one extra proton**.



- This imbalance prevented complete **annihilation** of matter and antimatter, allowing matter to persist and aggregate into cosmic structures.

Challenges in Explaining the Matter-Antimatter Asymmetry

- **Limitations of the Standard Model:**

- The **Standard Model of particle physics** does not fully account for the **matter dominance** over antimatter.
- To explain this asymmetry, theories must satisfy the **Sakharov conditions**:
 1. **CP Symmetry Violation**
 2. **Baryon Number Violation**
 3. **Out of Thermal Equilibrium Interactions**

Sakharov Conditions for Matter Dominance

1. **Baryon Number Violation:**

- Processes must exist where particles like **protons (baryons)** can be **created or destroyed** in the early universe.

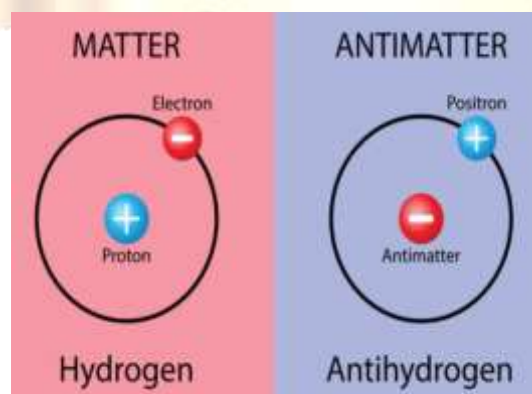
2. **CP Symmetry Violation:**

- The laws of physics must differentiate between matter and antimatter under certain conditions, breaking **CP symmetry**.

3. **Out of Thermal Equilibrium:**

- Early universe conditions should prevent particles and antiparticles from converting back and forth equally, maintaining an **imbalance** that favors matter survival.

Recent Progress in Understanding Asymmetry





- **2024 Study on Meson Decays:**
 - Recent research indicates that **meson decays** could fulfill the **CP symmetry violation** aspect within the **Standard Model**.
 - This involves the role of **hypothetical particles** that were abundant in the early universe but are rare today.
 - The proposed mechanism aligns with **quantum field theory**, offering partial fulfillment of the **Sakharov conditions**.

Future Directions and Challenges

- **Advancing the Understanding:**
 - The recent findings address **one of the Sakharov conditions** (CP symmetry violation).
 - **Remaining Challenges:**
 - **Baryon Number Violation** and **Out of Thermal Equilibrium** conditions still require comprehensive explanations.
 - Ongoing research aims to bridge these gaps, further elucidating the **matter-antimatter asymmetry** in the universe.

Key Points Highlighted

- **Antiparticles** are essential in understanding the **symmetry of quantum mechanics** but are **rare** in the universe.
- The **matter-antimatter asymmetry** is a fundamental question in cosmology and particle physics.
- The **Standard Model** lacks a complete explanation for why **matter dominates** over antimatter.
- The **Sakharov conditions** provide a framework for theories addressing this asymmetry.
- **Recent studies** on **meson decays** offer progress towards satisfying the **CP symmetry violation** condition.

Source: <https://www.thehindu.com/sci-tech/science/proposed-mechanism-antimatter-absence-sakharov-conditions-standard-model/article68964127.ece#:~:text=Antiparticles%20are%20an%20inevitable%20consequence,eerie%2C%20that's%20because%20it%20is.>