Exotic antimatter finding may clarify cosmic symmetries

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Courtesy of Brookhaven National Laboratory
and World Science staff

Physicists say they have detected the heaviest "anti-nucleus" to date, a rare specimen of a sort of mirror-image form of ordinary matter.

The finding may shed light on cosmic symmetries, and asymmetries, that explain why most of the antimatter originally produced at the birth of the universe is gone, according to scientists.

The STAR Detector (courtesy Brookhaven Nat'l Lab)

An antiparticle is a variant of one of the normal building blocks of matter that has equal weight, but is opposite in electrical charge and certain other respects, to its "normal" particle counterpart. As a nucleus is the core of an ordinary atom, an anti-nucleus is the core of an "anti-atom."

The newfound anti-nucleus also contains the first example of a smaller, equally exotic component building block that physicists call an anti-strange quark.

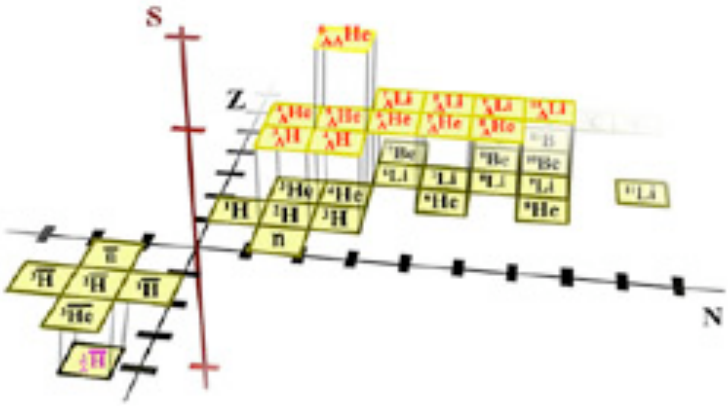
The discovery "may have unprecedented consequences for our view of the world," said theoretical physicist Horst Stoecker, Vice President of the Helmholtz Association of German National Laboratories. "This antimatter pushes open the door to new dimensions in the nuclear chart — an idea that just a few years ago, would have been viewed as impossible."

The finding, at the U.S. Department of Energy's Brookhaven National Laboratory in New

York, may also help shed light on the workings of compact celestial objects known as neutron stars, researchers said.

The nucleus of a normal atom on Earth consists of building blocks called protons and neutrons, which in turn contain smaller components known as quarks. These quarks appear in two types, arbitrarily called “up” and “down” varieties.

The standard Periodic Table of Elements is a grid arranged by number of protons, which determine each chemical element’s properties in its basic interactions with other elements.



The "3-D chart of the nuclides." The familiar Periodic Table arranges the elements according to their atomic number, Z, which determines the chemical properties of each element. Physicists are also concerned with the N axis, which gives the number of neutrons in the nucleus. The third axis represents strangeness, S, which is zero for all naturally occurring matter, but could be non-zero in the core of collapsed stars. Antinuclei lie at negative Z and N in the above chart, and the newly discovered antinucleus (magenta) now extends the 3-D chart into the new region of strange antimatter. (courtesy Brookhaven Nat'l Lab)

But physicists also use a more complex, three-dimension chart which adds information on the differing number of neutrons that can occur in samples of each element. The 3-D chart also indicates a number known as “strangeness,” which depends on the presence of so-called “strange” quarks. Nuclei containing one or more strange quarks are called hypernuclei.

For ordinary matter without strange quarks, the strangeness value is zero and the chart is flat. Hypernuclei are charted on a separate grid, which is shown as if hovering above the standard table. The new discovery of strange antimatter with an antistrange quark—an “antihypernucleus”—marks the first entry below the standard grid, scientists explain.

The bizarre particle was detected as a result of high-speed collisions of gold nuclei at the Relativist Heavy Ion Collider, the Brookhaven laboratory’s atom smasher. The results were published March 4 on the online edition of the research journal *Science*.

The study of the new antihypernucleus also yields a valuable sample of hypernuclei, and has implications for our understanding of the structure of collapsed stars, called neutron stars, researchers said. “The strangeness value could be non-zero in the core of collapsed stars,” said Jinhui Chen, one of the lead authors, of the Shanghai Institute of Applied Physics and a postdoctoral researcher at Kent State University in Ohio. The new measurements “will help us distinguish between models that describe these exotic states of matter.”

The findings also pave the way for exploring violations of fundamental symmetries between matter and antimatter that occurred in the early universe, making possible the very existence of our world, physicists added.

Smashups between atomic nuclei at the collider are believed to fleetingly reproduce conditions that existed a minuscule fraction of a second after the Big Bang, which scientists believe gave birth to the universe as we know it some 13.7 billion years ago.

In both events, quarks and antiquarks emerge with equal abundance, according to physicists. At the laboratory, among the collision fragments that survive to the final state, matter and antimatter are still measured as close to equally abundant. In contrast, antimatter appears to be largely absent from the present-day universe.

“Understanding precisely how and why there’s a predominance of matter over antimatter remains a major unsolved problem of physics,” said Brookhaven physicist Zhangbu Xu, another one of the lead authors. “A solution will require measurements of subtle deviations from perfect symmetry between matter and antimatter, and there are good prospects for future antimatter measurements at RHIC [Relativist Heavy Ion Collider] to address this key issue.”

In a single collision of gold nuclei at the collider, many hundreds of particles burst out at the point of the crash. Most of these don’t actually come from the previously existing, colliding objects as such. Rather, they are formed from the energy of the collision, by the conversion of energy into mass in accordance with Einstein’s famous equation $E = mc^2$.

The particles leave telltale tracks in a detector hooked up to the collider, called the STAR detector. Scientists analyzed about a hundred million collisions to spot the new antinuclei, which aren’t directly detectable themselves but are identifable through the byproducts into which they disintegrate. Altogether, 70 specimens of the new antinucleus were detected.

STAR detector scientists, who come from 54 institutions in 13 countries, say they should be able to discover even heavier antinuclei soon. Theoretical physicist Stoecker and his team have predicted that strange nuclei around double the mass of the newly discovered state should be particularly stable.