Spectrum of anti-hydrogen observed

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The ALPHA-2 (Anti-Hydrogen Laser Physics Apparatus) experiment has made the first observations comparing the light emitted from hydrogen atoms made of antimatter to the light emitted from hydrogen atoms made of ordinary matter. The results indicate that the underlying characteristics of matter and antimatter differ by at most 200 parts per trillion, a significant milestone for research into antimatter and particle physics in general.

ALPHA is one of many international scientific collaborations operating out of the CERN (European Organization for Nuclear Research) laboratories near Geneva, Switzerland. It generates and traps atoms of anti-hydrogen, the antimatter counterpart of the simplest atom, hydrogen, to allow for precision comparisons between the two in order to more fully understand the underlying physics governing antimatter.

The exact nature of antimatter is one of the outstanding questions in modern physics. Antimatter was first hypothesized by Paul Dirac in 1928 and worked through more carefully by Dirac and Robert Oppenheimer in 1931. They predicted that certain physical processes would produce particles identical to the well-known electron or proton, except that they would have an opposite electric charge. While the idea was met with some scepticism in the physics community, the existence of the “anti-electron” (more commonly known as a positron) was experimentally verified in 1931 by Paul Anderson. Since then, antimatter equivalents have since been observed for all known fundamental particles.

What has puzzled scientists for nearly a century, however, is the imbalance between the amounts of normal matter and antimatter in the universe. The Standard Model, the most advanced understanding of fundamental physics to date, predicts that there should have been equal amounts of matter and antimatter in the moments after the Big Bang, and thus in the rest of the cosmos. This contradicts the entirety of human experience on Earth and every astronomical observation, which all show that everything seems to be made solely from one half of this primordial material, ordinary matter.

Moreover, when a particle of matter meets its antiparticle, they both annihilate, demonstrating Einstein’s equivalence between mass and energy as both particles transform into radiation. Given that, the Standard Model also predicts that no astronomical structures should have developed, with everything constantly changing from particles to light and vice versa, ad infinitum.

The current explanation is that while the physics underlying the Big Bang produced an equal proportion of matter and antimatter, a hypothesized and as-yet-unexplained phenomenon caused a slight imbalance in this process, so that after wholesale annihilation one particle per billion of ordinary matter survived. These remnant particles are what we now call matter, with antimatter existing only as an exotic particle observed in cosmic rays, nuclear fusion and other high-energy phenomenon.

ALPHA provides a new tool to examine the root cause of the matter-antimatter asymmetry by examining the wavelength of light emitted from a trapped anti-hydrogen atom as the atom’s electron transitions between energy levels. This wavelength (analogous to colour) has been used to learn about the internal structure of normal hydrogen for decades and has now been used by the researchers of the ALPHA collaboration to begin similar studies of anti-hydrogen.

As ALPHA spokesperson Jeffrey Hangst explained, “Using a laser to observe a transition in anti-hydrogen and comparing it to hydrogen to see if they obey the same laws of physics has always been a key goal of antimatter research.”

To produce anti-hydrogen, ALPHA takes 90,000 antiprotons produced by CERN's Antiproton Decelerator and mixes those with 1.6 million positrons, yielding approximately 25,000 anti-hydrogen atoms per mixing. From this, an average of 14 anti-atoms are captured for study. While the number of anti-atoms captured per mixing may seem small, it is an order of magnitude greater than what has been achieved in previous studies. This enables such high precision in the measurements.

The main technical challenge facing ALPHA is keeping the anti-hydrogen from interacting with any hydrogen and being converted to energy, as described above. To avoid this, the atoms are stored in a vacuum and suspended in a strong magnetic field generated by powerful electromagnets, using techniques that have been refined since CERN first produced anti-hydrogen in 1995.

The anti-hydrogen atoms are then manipulated using precisely tuned laser beams inserted through the windows of the vacuum chamber. By observing how the anti-hydrogen reacts to the laser and the magnetic field, physicists are able to work out the internal properties of anti-hydrogen, which so far have not shown any fundamental difference from those of hydrogen.

While this does not shed any new light on the difference between matter and antimatter, it does provide a promising new way forward. Even now, the ALPHA collaboration is developing a number of upgrades and new techniques to increase the precision of their measurements in an attempt to find and measure any matter and antimatter asymmetries. The work occurs alongside other collaborations at CERN, including ASACUSA and BASE, all of which are working to penetrate this peculiar mystery.

Video: The ALPHA experiment observes light spectrum of antimatter for the first time