Cold antihydrogen

Tom W. Hijmans

The production of antihydrogen, the antimatter equivalent of the hydrogen atom, at low temperatures is an impressive feat. It also raises the possibility of searching for fundamental differences between matter and antimatter.

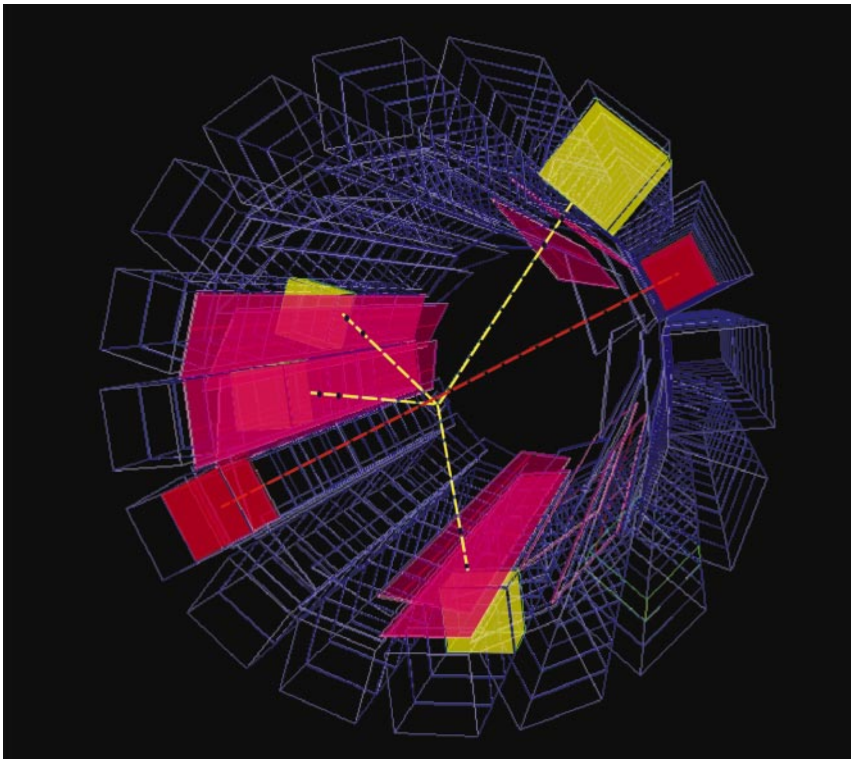
On page 456 of this issue, scientists working at the European Centre for Nuclear Research (CERN), in Geneva, report the first production of cold antihydrogen atoms[1]. This is a crucial step towards an eagerly sought goal in physics — the realization of magnetically trapped neutral antimatter.

The ordinary matter that makes up ourselves and the world around us is based on elementary particles such as protons, neutrons and electrons. All of these particles have partners known as antiparticles. Antimatter is like a mirror image of ordinary matter, the most notable difference being that the electric charges of antiparticles are the opposite of those of their normal-matter counterparts. Matter and antimatter are deceptively similar: were we to live in an antimatter world, and be composed of antimatter ourselves, we would not be able to tell.

When matter and antimatter meet, however, dramatic things happen. When a particle collides with its antiparticle, the result is the complete annihilation of both. All that remains is a burst of radiation, the energy E of which is given by Einstein's famous equation $E = mc^2$, where m is the total mass of the particles involved in the collision and c is the speed of light. It is this complete transformation of mass into energy that has made antimatter a firm favourite in the world of science fiction.

Many physicists believe that the study of neutral antimatter, such as the antihydrogen atom, holds the key to questions of fundamental importance in physics — in particular, whether there is some fundamental difference between matter and antimatter, and the mystery of why the Universe appears to be overwhelmingly filled with matter. The obvious challenge for experimentalists is that their laboratories and measuring instruments are made of ordinary matter, and antiparticles will self-destruct on first contact with the apparatus.

The proposed solution is 'wall-free' magnetic confinement or trapping. The idea is to use an arrangement of magnetic fields to push the anti-atoms away from the walls of the apparatus and keep them suspended in space. Non-destructive precision experiments could then be carried out on the anti-atoms, using laser light, for example. Unfortunately, the magnetic forces that can be exerted on electrically neutral objects such as anti-atoms are rather limited. Hence the need for low-temperature experiments: unless the atoms are moving at the very low speeds characteristic of temperatures just a few degrees above absolute zero, they will simply pierce the magnetic confinement and hit the walls.



ATHENA/CERN

Figure 1 **Antihydrogen annihilation. The ATHENA experiment has produced the first cold anti-atoms[1], detected through their destruction in collisions with matter particles. The annihilation of the antiproton produces secondary particles, which, picked up in the surrounding detectors (blue), can be traced back (yellow dashed lines) to the annihilation point. Similarly, the annihilation of the positron produces a distinctive back-to-back two-photon signature (red dashed lines). The overlap of the two annihilation points signifies that the positron and antiproton were bound together in an atom of antihydrogen.**

It is sometimes argued that the considerable effort needed to make antihydrogen can only be justified by the proposed experiments that will seek out possible differences between matter and antimatter. There are sceptics who express reservations about such experiments, pointing to the high likelihood that no differences will be found. All agree, however, that if any difference were found, no matter how small, it would cause a big stir in physics. Personally, I consider the stable confinement of neutral antimatter to be valuable in itself. Just to be able to look inside this untouchable realm that is similar to, but at the same time incompatible with, the world we live in has great aesthetic appeal.

Antihydrogen is the simplest possible antimatter atom: it consists of a positively charged positron, the antiparticle of the familiar electron, orbiting an antiproton that has negative electric charge. At CERN, two international collaborations, ATRAP and ATHENA, have for several years been inching towards the synthesis of antihydogen from its charged constituents at low temperature. An

Further News and Views coverage appears on pages 493–497, with three articles discussing papers on the genome sequences of malaria parasites, and of the mosquito that is the principal vector of the disease in humans.

essential innovation introduced by ATRAP was the nested Penning trap[2], a clever device that solves the problem of how to confine oppositely charged positrons and antiprotons simultaneously. ATRAP came quite close to producing antihydrogen last year[3] but it is ATHENA that now reports success[1].

The antiprotons supplied to ATRAP and ATHENA from a particle accelerator move at almost the speed of light. First, this velocity must be reduced by an enormous factor, and during this process many particles are lost. The other constituents, the positrons, are emitted by a radioactive source and must also be slowed down to be useful. Having as many particles as possible to begin with is the key to success. The formation of an anti-atom in collisions between antiparticles is a rare event and, even when formed, most anti-atoms are not detected: about 130 antihydrogen atoms were observed in the ATHENA experiment, out of an estimated 50,000 produced.

Unfortunately, it is not yet possible to trap the anti-atoms. In fact, they reveal their presence only through their destruction in collisions with the apparatus walls (Fig. 1). An annihilating antiproton produces a number of energetic particles that fly off in various directions and these secondary particles leave directional traces in the detectors that surround the anti-atom sample. Like a ballistics expert on the scene of a crime who reconstructs the position of a gunman by tracing back trajectories from scattered bullet holes, the physicists are able to determine precisely the location of the antiproton annihilation.

It is then necessary to prove that the antiproton was not an isolated particle, but part of an antihydrogen atom. To show this, it is sufficient to find a positron that has also been annihilated at the same position and precisely the same time. The tell-tale signature of such a positron–electron annihilation in the wall material is the emission of two γ-ray particles of well-defined energy (512 keV each) that leave the 'scene of the crime' in exactly opposite directions.

The production of cold antihydrogen is a milestone, but it is just the beginning. Taking the next step towards trapping anti-atoms is fraught with difficulties. For one thing, the arrangement of magnetic fields needed to create a nested Penning trap is not optimal for trapping neutral anti-atoms. But the field is buzzing with ideas and ATHENA's progress will surely provide the motivation for researchers to face these challenges. ■

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Evolutionary biology

Death in the slow lane

Marcel Cardillo and Adrian Lister

Were the Late Pleistocene extinctions of large mammals the result of climate change or big-game hunting by humans? Reconstructing the biology of extinct species provides clues to the answer.

What caused the Late Pleistocene 'megafaunal' extinctions — the episode between about 50,000 and 10,000 years ago when mammoths, giant ground sloths, giant kangaroos (Fig. 1) and dozens of other large vertebrate species became extinct? The 'overkill' theory holds that human hunters drove the megafauna to extinction. An extreme form of the overkill theory is the 'blitzkrieg' model, in which the humans of Pleistocene times were big-game hunters, selectively and rapidly hunting the largest species to extinction as they swept through newly colonized continents. Others argue that the megafauna were killed off by climate and vegetation change at the end of the last ice age.

Usually, these theories are assessed by using the fossil record to compare the timing of megafaunal extinctions with human arrival on continents and climate change. But as he describes in a paper published in *Proceedings of the Royal Society*[1], Chris Johnson has taken a fresh approach by systematically comparing the traits of extinct mammal species with those that survived. He finds that it was not large size that predisposed species to extinction, but low reproductive rate. This does not fit in with the blitzkrieg view of events.

Johnson models the close relationship between body size and reproductive rate within taxonomic families of living mammals, and uses this to infer reproductive rates for extinct members of the same families. He cleverly uses a between-family comparison to sidestep the potential circularity of this method, and then shows that the likelihood of extinction was higher for groups with lower reproductive rates, regardless of their body size. Even relatively small mammals became extinct if their fecundity was low enough. Strikingly, the threshold reproductive rate at which the chance of extinction exceeds 50% is roughly the same — about one offspring per female per year — for all groups examined, from 700-gram lemurs to one-tonne cattle. It seems that what was lost during the Pleistocene was not so much the megafauna as the 'bradyfauna' — a whole way of life based on slow life-history.

These results run counter to the idea of extinction by rapid blitzkrieg because, if larger mammals were being selectively hunted, body size as well as reproductive rate should be an important determinant of extinction. However, Johnson noticed another interesting pattern in his data. Those mammal species that bucked the trend, surviving to the present day despite low reproductive rates, tend to be arboreal, nocturnal or inhabitants of dense forests, high latitudes or high altitudes — all of which ought to protect them from human hunters. Johnson interprets this as evidence in favour of more general overkill, where species of all body sizes were harvested.

Johnson's findings complement those of Alroy[2], who modelled the effects of human hunting on Late Pleistocene extinctions in North America. Without assuming human preference for big game, Alroy's model matched the observed pattern of large-mammal extinction. The two studies agree that even low levels of hunting could have led to extinction: Johnson suggests that, because of the slow reproductive rates of the victims, extinctions need not have occurred rapidly, while Alroy gives a median extinction date in North America of about 900 years after the Clovis hunter–gatherers migrated into the continent from Asia about 13,400 years ago. Whether or not this can be considered rapid blitzkrieg is a matter of perspective — ecologists and palaeontologists are used to working at very different timescales.

Johnson's result leaves the effects of climate change an open question. Species with slow reproductive rates would have been the most vulnerable to environmental degradation as well as to hunting. For Australia, it has been suggested that during the Last Glacial Maximum (around 20,000 years ago), expansion of the arid interior at the expense of the lush coastal zone was a causal factor in Pleistocene extinctions. The finding that, even in Australia, survivors tended to live in forest or other cryptic habitats, could be interpreted as evidence against this climate model. Moreover, some dates for Australian fossil sites[3,4] place megafaunal extinctions well before the Last Glacial Maximum, at around the time of the first evidence of humans.

Perhaps a similar approach to Johnson's could be used to test predictions of the climate hypothesis — comparing, say, extinction patterns in Australian taxa such as reptiles and mammals that differ in their ability to cope with extreme drought. Further, the climatic models for other continents are very different and need to be tested separately. The disappearance of the