Cooling technique allows easier measurements of key particle property

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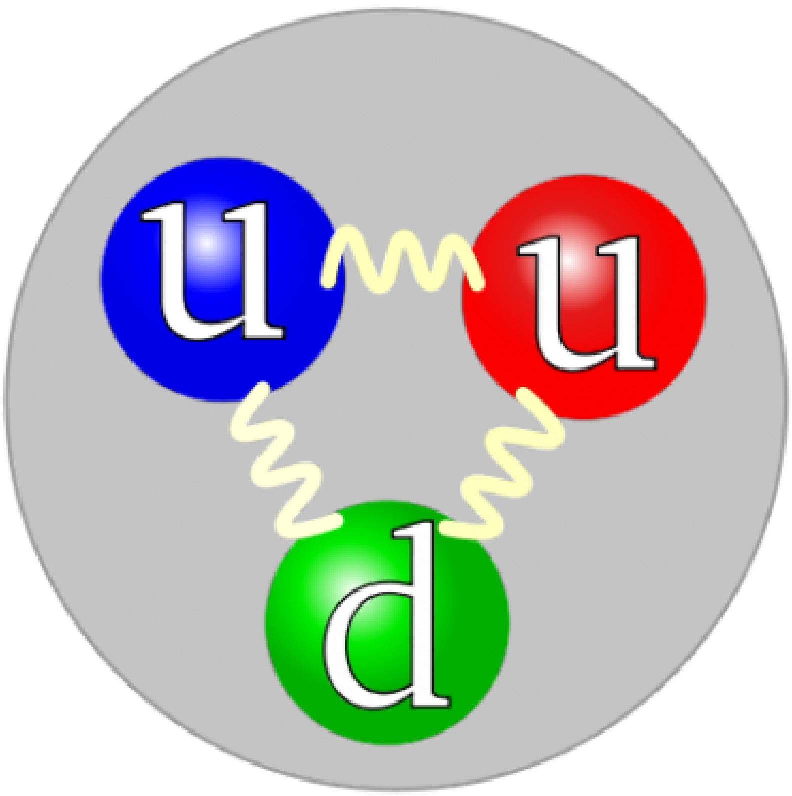

The quark structure of the proton. There are two up quarks in it and one down quark. The strong force is mediated by gluons (wavey). The strong force has three types of charges, the so-called red, green and the blue. Note that the choice of green for the down quark is arbitrary; the "color charge" is thought of as circulating among the three quarks. Credit: Arpad Horvath/Wikipedia

Scientists from the BASE-collaboration, led by RIKEN scientists, have developed a new cooling method that will allow easier measurements of a property of protons and antiprotons called the magnetic moment. This is one of the properties that is being investigated to solve the mystery of why our universe contains matter but almost no antimatter.

Our universe should, under the standard model, have equal amounts of matter and antimatter, but in reality it does not. To find out why, scientists around the world are trying to discover tiny differences between the two that could solve the mystery. One promising avenue is to explore whether there are differences in the magnetic moment of the proton and antiproton, and the BASE experiment, based at CERN, is trying to determine this. Using a sophisticated device—a Penning trap capable of capturing and detecting a single particle—the BASE team in the past was able to improve the precision of proton and antiproton magnetic moment measurements by a factor of thirty and by more than three orders of magnitude, respectively, leading to a test of matter/antimatter symmetry at the level of 1.5 parts in a billion, finding essentially that the magnets in the proton and the antiproton are similar to nine significant figures.

One difficulty—among many—in carrying out such experiments is that to measure the magnetic moments precisely, the particles need to be kept at temperatures close to absolute zero, -273.15°C. In previous experiments the cold temperatures were prepared by using a technique known as "selective resistive cooling," which is time-consuming and, according to the researchers, "similar to throwing a dice with 100 faces, trying to roll a 1."

For the current experiment, published in *Nature*, the BASE collaboration reported the first ever demonstration of "sympathetic cooling" of a single proton by coupling the particle to a cloud of laser-cooled 9Be+ ions. Sympathetic cooling involves using lasers or other devices to cool one type of particle, and then using those particles to transfer the heat of the particle they wish to cool. With this technique, the group simultaneously cooled a resonant mode of a macroscopic superconducting tuned circuit with laser-cooled ions, and also achieved the sympathetic cooling of a single trapped proton, reaching temperatures close to absolute zero.

The technique described in the recent paper is an important first step towards a considerable reduction of faces on the dice-manifold, with the vision of ideally reducing the surface to just one. "We are reporting an important first step, and the further development of this method will ultimately lead to an ideal spin-flip experiment, in which a single low-temperature proton will be prepared within just a few seconds. This will allow us to determine the particle's spin state in just one measurement that takes about a minute," says Christian Smorra, one of the scientists leading the study. "This is considerably faster than our previous magnetic moment measurements, and will improve both sampling statistics and the resolution of our systematic studies," adds Matthew Bohman, a Ph.D. student at the Max Planck Institute for nuclear Physics, Heidelberg and the first author of the study.

"In addition, the reported achievement has applications not only in proton/antiproton magnetic moment measurements. It adds general new technology to the tool-box of precision Penning-trap physics, and also has potential applications in other nuclear magnetic moment measurements, ultra-precise comparisons of charge-to-mass ratios in Penning traps, or even in enhancing the production of antihydrogen," adds Stefan Ulmer, spokesperson of the BASE collaboration and chief scientist at RIKEN Fundamental Symmetries Laboratory.

The BASE collaboration operates three experiments, one at the antimatter factory of CERN, one at the University of Hannover, and one at the University of Mainz, the laboratory where the new method was actually implemented. The reported study is a result of the joint collaboration between RIKEN, the German Max Planck Society, the Universities of Mainz, Hannover and Tokyo, the German metrology institute PTB, CERN, and GSI Darmstadt. The work was supported by the Max Planck, RIKEN, PTB center for time, constants and fundamental symmetries.

More information: Sympathetic cooling of a trapped proton mediated by an LC circuit, *Nature* (2021). DOI: 10.1038/s41586-021-03784-w , www.nature.com/articles/s41586-021-03784-w

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