Scientists mix matter and anti-matter to resolve decade-old proton puzzle

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The CEBAF Large Acceptance Spectrometer, or CLAS, in Jefferson Lab's Experimental Hall B was used to measure electrons during the experiment.

Fans of science and science fiction have been warned that mixing matter with anti-matter can yield explosive results. And that's just what physicists were counting on, in hopes of blowing wide open a puzzle that has confounded them for the last decade.

The puzzle comes from experiments that aimed to determine how quarks, the building blocks of the proton, are arranged inside that particle. That information is locked inside a quantity that scientists refer to as the proton's electric form factor. The electric form factor describes the spatial distribution of the quarks inside the proton by mapping the charge that the quarks carry.

Nuclear physicists have used two different methods to measure the proton's electric form factor. But the deeper that they probe inside the proton, the more the results from these two different methods disagree. Eventually, the measurements provided by one method amount to about five times the quantity yielded by the other. This huge discrepancy is much larger than the experimental uncertainty in the measurements.

"The proposed solution for the discrepancy is that the analysis of one set of measurements was too simplistic," says Larry Weinstein, a professor of physics at Old Dominion University. "And that if we include something that is known as the two-photon effect, they both should agree."

The effect is a result of the manner in which nuclear scientists conduct their probes of the proton. The proton is probed by bombarding it with energetic electrons and observing how the two particles interact. Most of the time, this interaction consists of the electron exchanging a single virtual photon with the proton. A virtual photon is just a packet of energy that an electron gives up to the proton as it collides with the particle. But sometimes, the electron interacts with the proton differently; it may conjure up two virtual photons that it passes on to the proton.

"Normally, when an electron scatters off of a proton or off of a nucleus, it does it by exchanging a single virtual photon. Like two skaters passing by each other, and one throws a medicine ball to the other; it helps push them apart," Weinstein explains. "Because the electromagnetic interaction is very weak, we expect that the second photon, second medicine ball, is only exchanged a few percent of the time. But that few percent effect could be big enough to explain this huge difference between the measurements of the proton's electric form factor."

So, nuclear scientists needed a good measurement of how often an electron is likely to generate two photons via this two-photon effect. But there was a big problem: no one had ever measured this effect, and calculating it to any level of accuracy was too difficult due to the complexity of the proton.

To get that quantity, Weinstein and his colleagues turned to mixing matter with anti-matter.

It turns out that, while measuring the two-photon effect directly may be too difficult to do now, the scientists could instead measure a different quantity that relates to the effect. The two-photon effect can be measured indirectly by noting how often the electron interacts with the proton and comparing that to how often the electron's anti-matter twin, the positron, interacts with the proton. The difference between electron and positron interactions calibrates the strength of the two photon effect and its effect on the form factor measurements.

Using the Continuous Electron Beam Accelerator Facility, or CEBAF, at the DOE's Thomas Jefferson National Accelerator Facility, Weinstein and his colleagues set out to make the measurement in the winter of 2010. They started with a beam of electrons, which they then passed through two gold foils and a few magnets to produce a beam composed of electrons and positrons. This beam was then directed onto the protons of a hydrogen target.

They then collected data on the electron-proton and positron-proton collisions with the CLAS spectrometer. Since an experiment like this had never been done before, it took them four years to analyze the data and extract precise results.

"There actually was a few percent difference. We got a few percent more positron-proton scattering events than electron-proton scattering events," Weinstein says. "So, our measurement agrees with the calculation, and the calculation accounts for most of the discrepancy between the two measurements of the proton's electric form factor."

According to the researchers, this means that the differences in the measurements of the proton's electric form factor, which provides information on how quarks are distributed inside the proton, can be accounted for by the two-photon effect.

Two other research groups, the VEPP-3 collaboration at Novosibirsk and the OLYMPUS collaboration at DESY, have also been measuring this effect, although with single beams of electrons that they compare to single beams of positrons. VEPP-3 measured similar results and OLYMPUS collaborators are still analyzing their data.

Now that the proton-puzzle is apparently resolved, nuclear scientists will further explore the proton's electric form factor, revealing where quarks are in the proton, and the proton's magnetic form factor, revealing how quarks are moving inside the proton, to gain better insight into how quarks build protons.

Two doctoral students were instrumental in conducting the experiment. Dipak Rimal, Florida International University, and Dasuni Adikaram, Old Dominion University, helped set up the equipment, stack shielding, and acquire, calibrate and analyze the data. Both graduated in May 2014.

More information: "Towards a Resolution of the Proton Form Factor Problem: New Electron and Positron Scattering Data" *Phys. Rev. Lett.* 114, 062003 – Published 10 February 2015. dx.doi.org/10.1103/PhysRevLett.114.062003

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