Extension – Reading on Frontier Research Topics based on high-precision hydrogen atom spectroscopy

Do Matter and Antimatter behave identically?

The only antimatter produced on Earth is anti-hydrogen consisting of an anti-proton and a positron. The ALPHA Collaboration at CERN can produce and trap anti-H atom long enough to study the Lyman lines and the fine structure.   The research is related to matter-antimatter asymmetry, i.e. why we are dominated by matter. Key papers from the ALPAH Collaboration are:

Observation of the 1S–2P Lyman-α transition in antihydrogen, Nature 561 (2018) 211-215. https://www.nature.com/articles/s41586-018-0435-1

Investigation of the fine structure of antihydrogen, Nature 578 (2020) 375-380. https://www.nature.com/articles/s41586-020-2006-5

How big is the proton?

Proton has something (quarks) in it. So it is not an elementary particle like the electron. It has a finite size of about fm (femtometer or 10^{-15} m), but what is the number in front? Is it 0.7 x 10^{-15} m or 0.8 x 10^{-15} m or something else? It is a fundamental question.

A traditional way of determining the size of a proton is to do electron-proton scattering (or electron-any nucleus scattering). Another way is to probe the atomic transitions to infer the size of a proton. If the proton is something like a charged sphere instead of a point charge, the energy levels of a hydrogen atom will be altered. These two different approaches have been carried out with great care and precision. For some years, they gave results that are different.

See the article in Science (Oct 2017) entitled "The Proton Size Revisited" http://science.sciencemag.org/content/358/6359/39 for the story.

Latest development in November 2019 was that electron-proton scattering experiment started to give results that are closer to that obtained by muonic-hydrogen spectroscopic measurements.

See "A small proton charge radius from an electron–proton scattering experiment", Nature 575 (2019) 147-150. https://www.nature.com/articles/s41586-019-1721-2

See also the news item "How big is the proton? Particle-size puzzle leaps closer to resolution", Nature 575 (2019) 269-270. https://www.nature.com/articles/d41586-019-03432-4

How did proton get its spin?

In studying the hyperfine structure of a hydrogen atom, the spin of the proton is invoked. Proton has spin s=1/2. There are quarks and gluons (binding the quarks) inside the proton. Quarks are spin-half particles as well. How could the constituents account for the observed proton's spin and proton's magnetic dipole moment? It is still an active research question. This problem is often referred to as the proton spin crisis.

See the article (March 2017) at https://phys.org/news/2017-03-proton.html

See Alexandrou *et al.* "Nucleon spin and momentum decomposition using lattice QCD simulations", Phys. Rev. Lett. **119**, 142002 (2017). The article was discussed in a softer introduction at https://phys.org/news/2017-10-proton-puzzle.html