The proton radius puzzle solved

Jean Louis Van Belle, 24 January 2020

Summary

The electron-proton scattering experiment by the PRad (proton radius) team using the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab measured the root mean square (rms) charge radius of the proton to be 0.831 fm, with a (statistical) STD of 0.007 fm.

Assuming all of the charge in the proton is packed into a single pointlike (elementary) charge and applying the ring current model to a proton, one gets a proton radius equal to 0.587 fm. The difference between the two values is a $\sqrt{2}$ factor. This may be explained by the fact that the magnetic field of the ring current is expected to extend beyond the current ring and/or the intricacies related to the definition of an rms charge radius.

We feel the measurement lends credibility to attempts to extend the Zitterbewegung hypothesis from electrons to also include protons and other elementary particles. In contrast, the measurement is hard to fit into a model of oscillating quarks that have partial charge only.

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If you follow the weird world of quantum mechanics with some interest, you will have heard the latest news: the 'puzzle' of the charge radius of the proton has been solved. To be precise, a more precise electron-proton scattering experiment by the PRad (proton radius) team using the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab has now measured the *root mean square* (rms) charge radius of the proton as[1]:

$$r_p = 0.831 \pm 0.007_{stat} \pm 0.012_{syst} \text{ fm}$$

If a proton would, somehow, have a pointlike elementary (electric) charge in it, and if it is in some kind of circular motion (as we presume in *Zitterbewegung* models of elementary particles), then we can establish a simple relation between the magnetic moment (μ) and the radius (a) of the circular current.

Indeed, the magnetic moment is the current (I) times the surface area of the loop (πa^2), and the current is just the product of the elementary charge (q_e) and the frequency (f), which we can calculate as $f = c/2\pi a$, i.e. the velocity of the charge[2] divided by the circumference of the loop. We write:

$$\mu = \mathrm{I} \cdot \pi a^2 = \mathrm{q_e} c \frac{\pi a^2}{2\pi a} = \mathrm{q_e} c \frac{a}{2} \approx 0.24 \ldots \times 10^{-10} \cdot a$$

Using the Compton radius of an electron ($a_e = \hbar/m_e c$), this yields the correct magnetic moment for the electron[3]:

$$\mu_e = (0.24 \ldots \times 10^{-10} \cdot 0.386 \ldots \times 10^{-12}) \approx 9.2847647043 \times 10^{-24} \text{ J/T}$$

What radius do we get when applying the $a = \mu/0.24\ldots\times10^{-10}$ relation to the (experimentally measured) magnetic moment of a proton? I invite the reader to verify the next calculation using CODATA values:

$$a = \frac{1.41 \ldots \times 10^{-26}}{0.24 \ldots \times 10^{-10}} = 0.587 \times 10^{-15} \text{ m}$$

When I first calculated this, I thought: that's not good enough. I only have the *order of magnitude* right. However, when multiplying this with √2, we get a value which fits into the 0.831 ± 0.007 interval. To be precise, we get this:

[1] See: https://www.nature.com/articles/s41586-019-1721-2. See also: https://www.jlab.org/prad/collaboration.html and https://www.jlab.org/experiment-research.

[2] *Zitterbewegung* models assume an electron consists of a pointlike charge whizzing around some center. The *rest* mass of the pointlike charge is zero, which is why its velocity is equal to the speed of light. However, because of its motion, it acquires an *effective* mass – pretty much like a photon, which has mass because of its motion. One can show the effective mass of the pointlike charge – which is a relativistic mass concept – is half the rest mass of the electron: $m_\gamma = m_e/2$.

[3] The calculations do away with the niceties of the + or – sign conventions as they focus on the *values* only. We also invite the reader to add the SI units so as to make sure all equations are consistent from a *dimensional* point of view. For the values themselves, see the CODATA values on the NIST website (https://physics.nist.gov/cuu/Constants/index.html).

$$(0.587\ldots\times10^{-15}\ \mathrm{m})\cdot\sqrt{2}\approx 0.8365\times10^{-15}\ \mathrm{m}$$

Of course, you will wonder: how can we justify the √2 factor? I am not sure. It is a *charge* radius. Hence, the electrons will bounce off because of the electromagnetic fields. The magnetic field of the current ring will envelope the current ring itself. We would, therefore, expect the measured charge radius to be larger than the radius of the current ring (*a*). There are also the intricacies related to the definition of a *root mean square* (rms) radius.

I feel this can*not* be a coincidence: the difference between our 'theoretical' value (0.8365 fm) and the last precision measurement (0.831 fm) is only 0.0055 fm, which is well within the statistical standard deviation (0.007 fm). Proton radius solved?

Maybe. Maybe not. The concluding comments of *Physics Today* were this: "The PRad radius result, about 0.83 fm, agrees with the smaller value from muonic and now electronic hydrogen spectroscopy measurements. With that, it seems the puzzle is resolved, and the discrepancy was likely due to measurement errors. *Unfortunately, the conclusion requires no new physics*." (my italics)

I wonder what kind of new physics they are talking about.

END