The proton radius puzzle solved?

Jean Louis Van Belle, 25 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.

When applying our two-dimensional 'oscillator model' to the proton, we found a radius of about 0.21. This radius equals the range parameter in Yukawa's formula. The ratio between the measured radius and this calculated distance is about 1/4, with a difference that is smaller than the systemic and statistical standard deviation. We have no explanation for this factor but it appears to be too precise to be a coincidence.

We, therefore, feel the new measurement of the proton radius 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.

Contents

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The charge radius of a proton

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]:

$$r_{\mathrm{p}} = 0.831 \pm 0.007_{\mathrm{stat}} \pm 0.012_{\mathrm{syst}}\ \mathrm{fm}$$

The ring current radius of a proton

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[2]), 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 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]:

[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] The *Zitterbewegung* model assumes 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: $m_\gamma = m_e/2$. The concept goes back to Alfred Lauck Parson (1915) and Erwin Schrödinger, who stumbled upon the idea while exploring solutions to Dirac's wave equation for free electrons. It's always worth quoting Dirac's summary of it: "The variables give rise to some rather unexpected phenomena concerning the motion of the electron. These have been fully worked out by Schrödinger. *It is found that an electron which seems to us to be moving slowly, must actually have a very high frequency oscillatory motion of small amplitude superposed on the regular motion which appears to us. As a result of this oscillatory motion, the velocity of the electron at any time equals the velocity of light. This is a prediction which cannot be directly verified by experiment, since the frequency of the oscillatory motion is so high and its amplitude is so small. But one must believe in this consequence of the theory, since other consequences of the theory which are inseparably bound up with this one, such as the law of scattering of light by an electron, are confirmed by experiment.*" (Paul A.M. Dirac, *Theory of Electrons and Positrons*, Nobel Lecture, December 12, 1933)

[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

$$\mu_e = (0.24\ldots\times10^{-10}\cdot 0.386\ldots\times 10^{-12}) \approx 9.2847647043\times 10^{-24}\ \mathrm{J/T}$$

When applying the $a = \mu/0.24\ldots\times10^{-10}$ relation to the (experimentally measured) magnetic moment of a proton, we get the following value for the *ring current radius* of a proton:

$$a = \frac{1.41\ldots\times10^{-26}}{0.24\ldots\times10^{-10}} = 0.587\times10^{-15}\ \mathrm{m}$$

When we multiply this with √2, we get a value which fits into the 0.831 ± 0.007 interval:

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

The √2 factor is puzzling but may be explained. The magnetic field of the current ring, for example, will envelop 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, which we have not studied.[4]

We admit these are less than heuristic arguments. At the same time, we feel the √2 factor can*not* be a coincidence: the difference between the 'theoretical' 0.8365 fm value and the 0.831 fm measurement is only 0.0055 fm, which is well within the statistical standard deviation (0.007 fm).

The proton radius based on an oscillator model

Our particular interpretation of the *Zitterbewegung* model of an electron allows us to calculate another theoretical radius of the proton. We've explained the idea elsewhere[5] and, hence, we will not elaborate too much here. It involves a direct calculation of the Compton radius combining the $E = \hbar\cdot\omega$, $c = a\cdot\omega$ and $E = m\cdot c^2$ relations. When using the mass for an electron, we get:

$$a = \frac{c}{\omega} = \frac{c\cdot\hbar}{\mathrm{m}\cdot c^2} = \frac{\hbar}{\mathrm{m}\cdot c} = \frac{\lambda_C}{2\pi} \approx 0.386\times 10^{-12}\ \mathrm{m}$$

When applying the $E = \hbar\cdot\omega$, $c = a\cdot\omega$ and $E = m\cdot c^2$ relations to the mass/energy of proton (or a neutron[6]), we get this:

$$a_\mathrm{p} = \frac{\hbar}{\mathrm{m_p}\cdot c} = \frac{\hbar}{\mathrm{E_p}/c} = \frac{(6.582\times10^{-16}\ \mathrm{eV}\cdot s)\cdot(3\times10^{8}\ m/s)}{938\times10^{6}\ \mathrm{eV}} \approx 0.21\times10^{-15}\ \mathrm{m}$$

The result that we obtain here is about 1/4 of the experimentally measured value. This distance is exactly the same as the distance that we get for the range parameter a in Yukawa's formula, which is

view. For the values themselves, see the CODATA values on the NIST website (https://physics.nist.gov/cuu/Constants/index.html).

[4] The peak value of a sinusoidal wave and its rms are related to the √2 factor but, we admit, this may sound like a rather poor argument.

[5] See, for example, our previous paper: *the Metaphysics of Physics*, http://vixra.org/abs/2001.0453.

[6] The mass of a neutron is about 939,565,413 eV/c^2 and about 938,272,081 eV/c^2 for the proton. Hence, the energy *difference* is a bit less than 1.3 MeV. It is, therefore, very tempting to think a neutron might, somehow, combine a proton and an electron: the electron mass is about 0.511 MeV/c^2 and, hence, we may think of the remaining difference as some kind of binding energy—the attractive force between the positive and a negative charge, perhaps? These thoughts are, obviously, very speculative. We did explore some of these, however, in our paper on the nature of protons and neutrons (http://vixra.org/abs/2001.0104), and we very much welcome comments.

about 2 fm.[7] In fact, we can equate the range parameter a and the distance r with the $a_p = \hbar/m_p c$ value in the force formulas we get from the potential formulas and we'll see the electrostatic and nuclear force – which we'll denote as F_C and F_N respectively – are, effectively the same[8]:

$$F_C = -\frac{dV}{dr} = -\frac{q_e^2}{4\pi\varepsilon_0}\frac{1}{r^2} = -\frac{\alpha\hbar c}{r^2} = -\frac{\alpha m_p^2 c^2}{\hbar}$$

$$F_N = -\frac{dU}{dr} = -\frac{g_N^2}{4\pi}\cdot\frac{\left(\frac{r}{a}+1\right)\cdot e^{-\frac{r}{a}}}{r^2} = -\frac{g_N^2}{4\pi}\cdot\frac{2e^{-1}}{r^2} = -\frac{e\alpha hc}{4\pi}\cdot\frac{2e^{-1}m_p^2 c^2}{\hbar^2} = -\frac{\alpha m_p^2 c^2}{\hbar}$$

Using the *exact* value for a_p, we can calculate the ratio between the new experimental value of the proton and the ratio as calculated above more exactly as:

$$\frac{a_p}{r_p} = \frac{0.21\ldots}{0.831\ldots} \approx 0.253$$

Hence, the ratio differs from the ¼ ratio (0.25) by 1.2% only. Is this *good enough*?

The systemic and statistical variance of the measured radius add up to 0.012 + 0.007 = 0.019 fm, which is about 2.3% of the point estimate (0.019/0.831) so, yes, we think it is significant.

Conclusions

The concluding comments of *Physics Today* on the very precise measurement of the proton's *rms* charge radius 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. We get two different theorical radii of the proton from 'new physics' here, and their relation with the measured radius is strangely perfect:

1. The charge radius, which relates to the measured radius by a factor equal to √2; and
2. The 'oscillator' radius, which is 1/4 of the measured value.

Ratios like this suggest it should *not* be difficult to connect the numbers but then, somehow, it is. Hopefully, someone smarter than me will be able to connect the dots and come up with a realist interpretation of quantum mechanics combining the idea of an electromagnetic and a 'strong' force.[9] Till

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[7] See Aitchison and Hey's introduction to *Gauge Theories in Particles Physics*, Vol. 1, Chapter 1 ((*The Particles and Forces of the Standard Model*) , p. 16. To be precise, Aitchison and Hey there write the range parameter is ~ 2 fm. They don't explain this result. Hence, we must assume they use the same formulas.

[8] For the detailed calculations in regard to force formulas, see: http://vixra.org/abs/2001.0104. Note that we left the nuclear constant (υ_0) out because its numerical value is one. You can, of course, calculate the *exact* value using the CODATA values for the various constants. You should find a pretty decent value: about 0.0000174 N, if we are not mistaken.

[9] The weak force is supposed to explain why things fall apart, or why particles are unstable, rather than stable. We prefer to not think of decay or disintegration as a force. It is, in fact, the exact opposite of the idea of a force: a

that day, the words which Mr. Dirac wrote back in 1958, as the last paragraph in the last edition of his Principles of Quantum Mechanics, will continue to ring true:

> "Now there are other kinds of interactions, which are revealed in high-energy physics and are important for the description of atomic nuclei. These interactions are not at present sufficiently well understood to be incorporated into a system of equations of motion. Theories of them have been set up and much developed and useful results obtained from them. But in the absence of equations of motion these theories cannot be presented as a logical development of the principles set up in this book. We are effectively in the pre-Bohr era with regard to these other interactions. It is to be hoped that with increasing knowledge a way will eventually be found for adapting the high-energy theories into a scheme based on equations of motion, and so unifying them with those of low-energy physics." (Principles of Quantum Mechanics, 4th edition, p. 312)

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force is supposed to keep things together. In the same vein, we like to add we do not want to entertain the idea of messenger particles or force carriers – virtual photons, gluons, or whatever other bosons or metaphysical constructs that have been invented since Yukawa first presented these ideas. Indeed, it is unfortunate that – instead of realizing he was actually proposing the existence of a new charge – he used his formula to derive a hypothetical nuclear force quantum.