The electron model and Nature's constants

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Summary

This paper recaps our electron model – including our explanation of the anomaly – and offers some reflections on Nature's fundamental constants. We will also present a theoretical explanation of the radius of the *Zitterbewegung* charge – aka the classical electron radius – using an electromagnetic mass calculation. While, in the previous version of the paper, we limited ourselves to a classical (non-mainstream) explanation of Schwinger's α/2π factor, we also offer some reflections on a possible explanation of the higher-order factors in the anomaly of the magnetic moment of an electron. Finally, we offer some reflections on the distinction between the spin and orbital angular momentum of an electron.

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Introduction

The idea of a force combines (1) the idea of a charge – a force acts on a charge, right? – and (2) the idea of inertia—resistance to a change of the state of motion. Logically, this leads one to conclude that a charge should have some mass. Why? Because any force on a zero-mass charge would give it infinite momentum. A brief look at the (relativistically correct) force law makes this rather obvious:

$$\mathbf{F} = \mathrm{m}_v \cdot \boldsymbol{a} = \frac{\mathrm{d}(\mathrm{m}_v \cdot \boldsymbol{v})}{\mathrm{d}t} = \frac{\mathrm{d}\mathbf{p}}{\mathrm{d}t}$$

$$\mathrm{m}_v = \gamma \cdot \mathrm{m}_0 = \frac{1}{\sqrt{1 - v^2/c^2}} \cdot \mathrm{m}_0$$

The velocity *v* in the *inertial* reference frame (i.e. the reference frame of the object we would be looking at) is equal to zero: the Lorentz factor is, therefore, equal to γ = 1, and $m_v = m_0$. Hence, if we have a finite force **F** acting on a zero-mass object, its acceleration ***a*** has to be infinite so as to yield a finite $0 \cdot \infty$ product. It is, therefore, quite nice that our ring current model of an electron yields a non-zero rest mass for the pointlike charge inside of the electron. Let us quickly recap the basics of it.

The anomaly of the electron's radius

Most ring current or *Zitterbewegung* models of an electron assume the pointlike *zbw* charge is whizzing around the center of the *zbw* oscillation *at the speed of light*. We think that assumption is a mathematical idealization. This is why the anomalous magnetic moment is *not* an anomaly: the assumption that the elementary charge has no dimension or structure whatsoever is bound to result in an 'anomaly' between our measurements and these 'good theories' we have about the structure of electrons, photons and protons.[1]

Let us do some calculations. Because ħ and *c* have precisely *defined* values since the 2019 revision of SI units, we can calculate the Compton radius from the mass—not approximately, but *exactly*.[2] The CODATA value for the electron mass is equal to:

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[1] Mathematical idealizations are just what they are: we need the math and the mathematical ideas that come with it (including the ideas of nothingness and infinity) to describe reality – math was Wittgenstein's ladder to understanding – but Planck's quantum of action, and the finite speed of light, effectively tell us our mathematical ideas are what they are: idealized notions we use to describe a reality which is, in the end, quite finite. Something that has no dimension whatsoever probably exists in our mind only. As for the notion of a 'good theory', we refer to Dirac's remarks on gauge and renormalization theory.

[2] Note that the radius is inversely proportional to the mass. The Compton radius of a muon-electron or a proton, for example, is much smaller than the Compton radius of an electron. As for the term 'good theories', this is, obviously, a bit of a cynical reference to Dirac's 1975 comments on renormalization theories: "This so-called 'good theory' involves neglecting infinities which appear in its equations, neglecting them in an arbitrary way. This is just not sensible mathematics. Sensible mathematics involves neglecting a quantity when it is small – not neglecting it just because it is infinitely great and you do not want it!"

$$m_{CODATA} = 9.1093837015(28)\times10^{-31}\ \text{kg}$$

Based on this, we can calculate a theoretical electron radius based on a ring current model of the electron.[3] Interpreting *c* as the tangential velocity of the *zbw* charge – and also using the Planck-Einstein and mass-energy equivalence relation – we get the following theoretical value for the ring current radius of an electron:

$$a = \frac{c}{\omega} = \frac{c\hbar}{E} = \frac{c\hbar}{mc^2} = \frac{\hbar}{mc} = \frac{\lambda_C}{2\pi} \approx 0.38616\ \text{pm}$$

This is the Compton radius, and we interpret it as the effective radius for inelastic (Compton) scattering of photons. The Compton radius is to be distinguished from the radius of the pointlike *zbw* charge inside, which we will (later) calculate as $r_e = \alpha r_C = \alpha\hbar/m_e c$. We can also calculate the Compton radius from the CODATA value for the magnetic moment[4]:

$$\mu_{CODATA} = 9.2847647043(28)\times10^{-24}\ \text{J}\cdot\text{T}^{-1}$$

Indeed, the magnetic moment is the product of the current and the area of the loop, and the current is the product of the elementary charge and the frequency. The frequency is, of course, the velocity of the charge divided by the circumference of the loop. Because we assume the velocity of our charge is equal to *c*, we get the following radius value:

$$\mu = I\pi a^2 = q_e f\pi a^2 = q_e\frac{c}{2\pi a}\pi a^2 = \frac{q_e c}{2}a \Leftrightarrow a = \frac{2\mu}{q_e c} \approx 0.38666\ \text{pm}$$

We should note that we get a value that is slightly different from the theoretical $a = c/\omega = \hbar/mc$ radius: we have an anomaly. We can confirm this anomaly by re-doing this calculation using the Planck-Einstein relation to calculate the frequency:

$$\mu = I\pi a^2 = q_e f\pi a^2 = \frac{q_e\omega a^2}{2} \Leftrightarrow a = \sqrt{\frac{2\mu}{q_e\omega}} = \sqrt{\frac{2\mu\hbar}{q_e E}} = \sqrt{\frac{2\mu\hbar}{q_e mc^2}} \approx 0.38638\ \text{pm}$$

We again get a slightly different value. These approximate 0.38666 and 0.38638 pm values we get out of our radius calculation using the CODATA value for the magnetic moment are slightly *larger* than the theoretical $a = \hbar/mc$ value we get based on the mass or the Compton wavelength, which is 0.38616 pm—more or less.[5] So, yes, we do have an anomaly.

Hence, we will want to think of the radius based on the mass or the Compton wavelength as some kind of *theoretical* radius and so we will put it in the denominator. We can write it like we want, with or without some subscript: $a = a_{CODATA} = a_m = a_\lambda = a_C$. In contrast, we will write the radius based on our calculation using the magnetic moment as a_μ. We can then write the anomaly as[6]:

[3] NIST gives CODATA values for the Compton wavelength of an electron. It also gives a measure of the electron's classical electron radius, which is the Compton radius divided by the fine-structure constant. We will leave it to the reader to verify those values against our calculations and reflect about those results.
[4] We should put a minus sign as per the convention but, because we are interested in magnitudes here, we will omit it. It will, hopefully, confuse the reader *less*, rather than more.
[5] We encourage the reader to re-do the calculations so as to arrive at more precise results.
[6] We used the first of the two radii one can calculate from the magnetic moment. The reader can re-do the calculations using the second of the two anomalous radii.

$$\frac{a_\mu - a}{a} \approx 0.00115965 \Leftrightarrow \frac{a_\mu}{a} = 1.00115965 \ldots$$

You will immediately recognize the anomaly. It is, effectively, equal to about 99.85% of Schwinger's factor: $\alpha/2\pi = 0.00116141\ldots$

The anomaly of the electron's magnetic moment

Let us, for good order, also recalculate the anomaly of the magnetic moment. We will follow a slightly different presentation than the usual one but you will see the logic is not very different. We first calculate a new *theoretical* value for the magnetic moment using the Compton radius, which we will denote as μ_a. When writing it all out, we get this:

$$\mu_a = \mathrm{I}\pi a^2 = \mathrm{q_e} f \pi a^2 = \mathrm{q_e}\frac{c}{2\pi a}\pi a^2 = \frac{\mathrm{q_e}c}{2}a = \frac{\mathrm{q_e}}{2\mathrm{m}}\hbar \approx 9.27401 \ldots \times 10^{-24}\ \mathrm{J}\cdot\mathrm{T}^{-1}$$

We can now calculate the anomaly – against the CODATA value – once more[7]:

$$\frac{\mu_a - \mu}{\mu} = 0.00115965 \ldots$$

We get the same anomaly—not approximately but *exactly*. That is what we would expect: in the *zbw* or ring current model, the anomaly is not only related to the *actual* magnetic moment but to the *actual* radius as well. This should not surprise us: the magnetic moment is, of course, proportional to the radius of the loop.[8] Hence, if the *actual* magnetic moment differs from the theoretical one, then the *actual* radius must also differ from the theoretical one.

At this point, the reader may wonder how we get a theoretical value for the magnetic moment. We get it from the same ring current model. We can just equate the two formulas we presented for the magnetic moment:

$$\left.\begin{aligned} a &= \sqrt{\frac{2\mu\hbar}{\mathrm{q_e m}c^2}} \\ a &= \frac{2\mu}{\mathrm{q_e}c} \end{aligned}\right\} \Leftrightarrow \sqrt{\frac{2\mu\hbar \mathrm{q_e^2}c^2}{4\mu^2\mathrm{q_e m}c^2}} = \sqrt{\frac{\hbar \mathrm{q_e}}{2\mu \mathrm{m}}} = 1 \Leftrightarrow \mu = \frac{\mathrm{q_e}}{2\mathrm{m}}\hbar$$

The mass of the *zbw* charge

Our assumption is that the anomaly is not an anomaly at all. We get it because of our mathematical idealizations. We think the assumption that the electron is just a pointlike or dimensionless charge is non-sensical: when thinking of what might be going on at the smallest scale of Nature, we should abandon these mathematical idealizations: an object that has no physical dimension whatsoever does – quite simply – not exist.

[7] You should watch out with the minus signs here – and you may want to think why you put what in the denominator – but it all works out!

[8] We have a squared radius in the numerator of the formula for the magnetic moment, and a non-squared radius factor in the denominator.

Likewise, we should not assume that the pointlike *zbw* charge is whizzing around at *exactly* the speed of light. It can be very *near c*, but not *quite* equal to *c*. Hence, its theoretical rest mass will also be very close to zero, but not *exactly* zero. As a result, we will have some *real* radius *r* that is probably *not quite* equal to the Compton radius $a = ħ/mc$ as well. Taking the ratio of the theoretical and actual magnetic moment, we get the anomaly:

$$\frac{\mu_a}{\mu_r} = \frac{\frac{q_e}{2m}\hbar}{\frac{q_e v}{2}r} = \frac{\hbar}{m \cdot v \cdot r} = \frac{c \cdot a}{v \cdot r}$$

Now, we know the anomaly is *very* nearly equal to 1 + α/2π. Hence, for practical purposes – we think a 99.85% explanation is pretty good – we may just equate the expression above with 1 + α/2π to get this:

$$1 + \frac{\alpha}{2\pi} = \frac{2\pi + \alpha}{2\pi} = \frac{c \cdot a}{v \cdot r} \Leftrightarrow v \cdot r = \frac{2\pi \cdot c \cdot a}{2\pi + \alpha} = \frac{2\pi \cdot c \cdot \frac{\hbar}{mc}}{2\pi + \alpha} = \frac{h}{m(2\pi + \alpha)} \Leftrightarrow L = m \cdot v \cdot r = \frac{h}{2\pi + \alpha}$$

So now we need to answer the question: what is the real velocity *v* and what is the real radius *r* of our *zbw* charge? We will come to that. We first ask the reader to note something quite essential here:

Mainstream quantum mechanics assumes angular momentum must come in units of ħ, and mainstream physicists think that is a direct implication of – or even an equivalent to – the Planck-Einstein law: E = *h*·*f* = ħ·ω. The calculation above brings some nuance to this statement: angular momentum does *not* come in *exact* units of ħ. There is an anomaly, and we think the anomaly is part and parcel of Nature.

In contrast, we must believe the Planck-Einstein relation to be true—not approximately but *exactly*. Hence, we must believe that the frequency *f* or ω of the *Zitterbewegung* oscillation is, effectively equal to *f* = E/*h* or ω = E/ħ, *precisely*. If we believe that to be true, then the following relations *explain* the anomaly[9]:

$$\frac{\mu_a}{\mu_r} = 1 + \frac{\alpha}{2\pi} = \frac{c \cdot a}{v \cdot r} = \frac{\omega \cdot a^2}{\omega \cdot r^2} = \frac{a^2}{r^2} \Leftrightarrow r = \frac{a}{\sqrt{1 + \frac{\alpha}{2\pi}}} \approx 0.99942 \cdot \frac{\hbar}{mc}$$

We get a radius that is slightly *smaller* than the theoretical *a* = ħ/m*c* radius. Does that make sense? It does: if the real and theoretical frequency are the same, and if the real tangential velocity of our zbw charge (*v*) is slightly smaller than the speed of light (*c*), then the real radius must be slightly smaller too. In fact, the *v*/*c* and *r*/*a* ratios must be exactly the same, as we can see from the tangential velocity formula:

$$1 = \frac{\omega}{\omega} = \frac{v/r}{c/a} \Leftrightarrow \frac{v}{c} = \frac{r}{a}$$

We can, therefore, calculate the relative velocity as:

[9] We are just using the tangential velocity formula here to do the substitution that is being done: $c = a \cdot \omega$ and $v = r \cdot \omega$ and – yes – we assume stable particles respect the Planck-Einstein relation, which we believe to be true—as opposed to the quantum-mechanical theorem in regard to angular momentum which, as mentioned, we believe to be very *nearly true*.

$$\beta = \frac{v}{c} = \frac{r}{a} = \frac{a}{a \cdot \sqrt{1 + \frac{\alpha}{2\pi}}} = \frac{1}{\sqrt{1 + \frac{\alpha}{2\pi}}} \approx 0.99942$$

Very nice! Now we can calculate what we wanted to calculate—the real rest mass of the pointlike *zbw* charge:

$$m_0 = \sqrt{1 - \beta^2} \cdot m_\gamma = \sqrt{1 - \beta^2} \cdot \frac{m_e}{2} = \sqrt{1 - \frac{1}{1 + \frac{\alpha}{2\pi}}} \cdot \frac{m_e}{2} = \sqrt{\frac{\alpha}{2\pi + \alpha}} \cdot \frac{m_e}{2} \approx 0.017 \cdot m_e \approx 0.034 \cdot m_\gamma$$

Hence, we arrive at the conclusion that the rest mass of the pointlike *Zitterbewegung* charge is equal to about 1.7% of the rest mass of the electron (m_e), or 3.4% of its relativistic mass (m_γ). Is this a credible result? We think so, but we will let the reader re-do the calculations.[10]

The basic results are this: we find an effective radius which is slightly *smaller* than the theoretical radius ($r \approx 0.99942 \cdot a$) because we also find a velocity which is also slightly smaller than the theoretical velocity ($v \approx 0.99942 \cdot c$).

The Planck-Einstein law and the clock speed of the electron

We based our calculations on the assumption that the Planck-Einstein relation must be true—not approximately but *exactly*. To be precise, we wrote that we must believe that the frequency f or ω of the *Zitterbewegung* oscillation is, effectively equal to $f = E/h$ or $\omega = E/\hbar$, *precisely*. This assumption was key to calculating the *real* ring current radius from the anomalous magnetic moment[11], for which we wrote:

$$\frac{\mu_r}{\mu_a} = 1 + \frac{\alpha}{2\pi} = \frac{c \cdot a}{v \cdot r} = \frac{\omega \cdot a^2}{\omega \cdot r^2} = \frac{a^2}{r^2} \Leftrightarrow r^2 = \frac{a^2}{1 + \frac{\alpha}{2\pi}} \Leftrightarrow r = \frac{a}{\sqrt{1 + \frac{\alpha}{2\pi}}}$$

Using the $v/c = r/a$ equation, we get the same relation between v and c:

$$\frac{v}{c} = \frac{r}{a} \Leftrightarrow v = \frac{rc}{a} = \frac{a \cdot c}{a \cdot \sqrt{1 + \frac{\alpha}{2\pi}}} \Leftrightarrow v = \frac{c}{\sqrt{1 + \frac{\alpha}{2\pi}}}$$

This *strongly* suggests our logic is impeccable: the Planck-Einstein relation is the Planck-Einstein relation—it is *not* slightly *off*! If it would be, we'd have to introduce subscripts and distinguish between ω_a and ω_r: a theoretical and an actual (angular) frequency. But so there is no need for it. We can calculate the real frequency to double-check that:

[10] We encourage the reader to re-do our calculations. Note that the approximate 0.38666 and 0.38638 pm values that we got out of our radius calculation using the CODATA value for the magnetic moment are slightly *larger* than the theoretical $a = \hbar/mc$ value we get based on the mass or the Compton wavelength.

[11] We briefly checked but we think other calculations did *not* depend on this assumption.

$$\omega_r = \frac{v}{r} = \frac{\dfrac{c}{\sqrt{1+\dfrac{\alpha}{2\pi}}}}{\dfrac{a}{\sqrt{1+\dfrac{\alpha}{2\pi}}}} = \frac{c}{a} = \omega_a$$

Hence, the Planck-Einstein relation is, effectively, an *absolute* law. It gives us the clock speed of the electron. In fact, in our interpretation of quantum physics[12], the Planck-Einstein relation will give you the clock speed of any elementary particle. It is, therefore, convenient to write it in this form:

$$\omega = \frac{\mathrm{E}}{\hbar} \Leftrightarrow f = \frac{\mathrm{E}}{h}$$

In contrast, we don't believe that angular momentum must come in *exact* units of ħ. There is always an anomaly: we think it is part and parcel of Nature. This brings us to the next question: we used an approximation. Schwinger's α/2π factor explains about 99.85% of the anomaly only: very good, but not good enough. We need some explanation for the remaining 0.15%—and preferably in terms of the fine-structure constant too!

We will immediately admit we do not have it ready. However, we think we can offer some useful reflections on this question, which may or may not offer a good basis for future progress. Before we get there, we should say a few words about the classical electron radius which, in our model, is the radius of the *zbw* charge itself.

An explanation for the classical electron radius

We think of the classical electron radius as the radius of the *zbw* charge inside of the electron. The CODATA value of the classical electron radius is this:

$$r_{\mathrm{CODATA}} = 2.8179403262(13)\times10^{-15}\ \mathrm{m}$$

This value corresponds, more or less[13], to the theoretical $r_e = \alpha r_C = \alpha\hbar/m_e c$ value when applying the $\alpha = \frac{q_e^2}{4\pi\varepsilon_0\hbar c}$ CODATA definition[14]:

$$r_e = \alpha\frac{\hbar}{\mathrm{m}c} = \frac{q_e^2}{4\pi\varepsilon_0\hbar c}\cdot\frac{c\hbar}{\mathrm{m}c^2} = \frac{q_e^2}{4\pi\varepsilon_0\mathrm{m}c^2} = 2.81794032666895\ldots\mathrm{fm}$$

[12] See our papers on the proton radius (https://vixra.org/abs/2001.0685), or on the nature of light and photons (https://vixra.org/abs/2001.0345).

[13] The reader should note the final digits of the two values are different.

[14] The use of point estimates yields a slightly different value but it is well within the standard error. Hence, we consider the results to be equivalent. NIST confirms our intuition here: the relative uncertainty on the Compton wavelength and the classical electron radius is of the same order: 3 and 4.5×10^{-10} respectively. A 50% or 1/2 factor—once more! We suspect it's the ½ factor in the effective mass.

Do we think this might be the real radius of the *zbw* charge at the core of the electron? We do. Richard Feynman gets the following interesting formula when calculating the electromagnetic mass or energy of a sphere of charge with radius *a*[15]:

$$U = \frac{1}{2}\frac{e^2}{a} = \frac{1}{2}\frac{q_e^2}{4\pi\varepsilon_0}\frac{1}{r_e} = \frac{1}{2}\frac{q_e^2}{4\pi\varepsilon_0}\frac{mc}{\alpha\hbar} = \frac{1}{2}\frac{q_e^2}{4\pi\varepsilon_0}\frac{4\pi\varepsilon_0\hbar mc^2}{q_e^2\hbar} = \frac{1}{2}mc^2$$

In fact, Feynman does not write it like this, but we inserted and used the $\alpha = \frac{q_e^2}{4\pi\varepsilon_0\hbar c}$ and $a = r_e = \alpha\frac{\hbar}{mc}$ identities above. The point is: we get only half of the (rest) energy or (rest) mass of the electron out of this assembly. Feynman was puzzled by that ½ factor: where is the other half? He should not have been puzzled by it: he is assembling the *zbw* charge here—*not* the electron as a whole. Hence, the missing mass is in the *Zitterbewegung* or orbital/circular motion of the *zbw* charge. We can now *derive* the classical electron radius from the formula above:

$$U = \frac{1}{2}\frac{e^2}{r_e} = \frac{1}{2}\frac{q_e^2}{4\pi\varepsilon_0}\frac{1}{r_e} \Leftrightarrow r_e = \frac{1}{2}\frac{q_e^2}{4\pi\varepsilon_0 U} = \alpha\frac{\hbar c}{2m_\gamma c^2} = \alpha\frac{\hbar}{m_e c} = \alpha r_C$$

This is a nice result. Mystery solved?

Maybe. Maybe not. We did gloss over some rather important details here. Feynman was assembling a thin spherical shell of charge here—as opposed to a uniformly charged *sphere* of charge, in which case the coefficient becomes 3/5 instead of 1/2.[16] So is our *zbw* charge a thin spherical shell of charge or a uniformly charged *sphere* of charge? Our honest answer is: we don't know. The formulas suggest the former—and that makes sense, instinctively: negative charges repel each other, so they are always on the outside of a conductor.

However, perhaps we should not push our classical ideas too far here. There are a few other – more important – things that don't make sense here. First, one should note that Feynman did not include the energy we associated with the spin of the *zbw* charge in this energy calculation. He only calculated *potential* energy when assembling the elementary charge by bringing infinitesimally small charges together. This undermines the logic of the derivation above. More importantly, the $m_e/2$ mass of our *zbw* charge is relativistic mass in our model: the pointlike *zbw* charge only acquires its $m_\gamma = m_e/2$ mass because it is *zittering* around at (almost) the speed of light. In other words, the ring current model tells us most of the energy is kinetic. To be precise, if our calculations are correct, then about 96.6% of the mass (or energy) of the *zbw* charge is kinetic.

So what can we say? Not all that much, for the time being. We don't think we managed to *fully* solve all of the quantum-mechanical mysteries. However, we do think that we have a perfectly consistent realist interpretation of quantum mechanics here. To be precise, we think we have a theory here which explains all of the mysterious *intrinsic* properties of an electron (its mass, its radius for elastic as well as inelastic scattering, and its magnetic moment) using common-sense physics. We, therefore, hope that we have managed to convince the reader that the assumption that the electron is just a dimensionless charge is non-sensical. When thinking of what might be going on at the smallest scale of Nature, we

[15] See: https://www.feynmanlectures.caltech.edu/II_28.html. The basic idea is to 'assemble' the elementary charge by bringing infinitesimally small charge *fractions* together.
[16] See: https://www.feynmanlectures.caltech.edu/II_08.html.

should abandon our mathematical idealizations: an object that has no physical dimension whatsoever does – quite simply – not exist. Pointlike and zero-dimension are not the same: the pointlike *zbw* charge has some (tiny) dimension.

We will now come to the question we raised earlier: how can we explain the remaining 0.15% of the anomaly?

The higher-order factors in the explanation of the anomaly

Schwinger's α/2π factor is a very good first-order factor: it explains about 99.85% explanation of the *measured* anomaly. However, we admit that's good but not good enough, so we write:

$$\frac{\mu_a - \mu}{\mu} = \frac{a_\mu - a}{a} = \frac{\alpha}{2\pi} + \cdots$$

So how can we explain the n^{th}-order factors (n > 1) that follow? We have not any detailed calculations here, but we think we have an logical explanation. As mentioned earlier, the $\mu = \mathrm{I}\pi r^2 = \mathrm{q_e} f \pi r^2 = \mathrm{q_e}\frac{v}{2\pi r}\pi r^2 = \frac{1}{2}\mathrm{q_e} r v$ tells us that the moment is proportional to the radius of the loop, and the factor of proportionality is $\mathrm{q_e}v/2$. Hence, electric charge that is closer to the theoretical *a* = ħ/m*c* radius will make a proportionally larger contribution to the magnetic moment. Hence, Feynman's conceptualization of the elementary charge – which is the *Zitterbewegung* charge in our model – as an assembly of infinitesimally small charges is useful here, once again. Let us illustrate this point by thinking about the *physicality* of what we are modeling here. We can re-write the equation above as follows[17]:

$$\frac{a_\mu - a}{a} = \frac{\alpha}{2\pi} + \cdots \Leftrightarrow a_\mu - a = (\alpha + \cdots)\cdot\frac{a}{2\pi}$$

This is a very interesting equation. *A priori*, one might have expected that the *difference* between the *a* = ħ/m*c* Compton radius and the *actual* radius *r* would be of the order of α·*a*. Why? Because α·*a* is the classical electron radius, which explains elastic scattering. We, therefore, think it is, in effect, the actual radius of the *zbw* charge inside of the electron. But we have a 1/2π factor here, and it is rather obvious that we cannot explain it away. This 1/2π factor is equal to about 0.16. It makes us think of the concept of the *effective center of charge*, which we used in an earlier attempt to provide a classical explanation for the anomalous magnetic moment.[18] As we accepted the idea of an effective radius of the *zbw* charge, we think the concept of an effective center of charge still makes sense. However, it obviously needs further tuning.

We will be honest here and admit we had hoped there would be some recursive logic in our electron model—and it is there! We calculated a so-called *real* radius of the *Zitterbewegung* based on the *definition* of the fine-structure constant, but that calculation is based on the idea of the *zbw* charge being pointlike. But then we say that the *zbw* charge is *not* pointlike – or not dimension-less. We say it has a radius itself: the classical electron radius—rather obvious, but we do need to make the point here.

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[17] We re-write the n^{th}-order factors (n > 1) here: we simply multiply them by 2π as we bring the 1/2π factor out of the brackets.
[18] We refer to our very first *Classical Calculations of the Anomalous Magnetic Moment* (https://vixra.org/abs/1906.0007), which we now think of as being useful but too simple. We think of it as being too simple because we were wedded to the idea of the *zbw* charge moving at lightspeed. This model makes much more sense, but it implies we have an actual radius that is actually *larger* than the theoretical *a* = ħ/mc radius—rather than smaller, as we assumed in the mentioned paper.

It is, therefore, rather obvious – to us: we hope the reader will see the point too – that some small corrections to the calculations will need to be made. We think these small corrections must, somehow, explain the n^{th}-order factors ($n > 1$) in the mainstream explanation of the anomalous magnetic moment. Let us move to the next topic requiring some attention.

Spin and orbital angular momentum

All of what we wrote above is related to *orbital* angular momentum. In an explanation of atomic orbitals, we also have the concept of *spin* angular momentum. It is easy enough to think of a *physical* interpretation of spin versus orbital angular momentum: the assumption that the spin angular momentum is related to the *zbw* charge spinning around its own axis comes quite logically. Thinking that the spin angular momentum may also be either up or down also comes quite logically. The question, then, is: what is the contribution of such spin angular moment to the magnetic moment?

All of what we have discussing above is, obviously, related to the *orbital* angular momentum of the ring current electron. We did *not* consider spin angular momentum. *A priori*, we would think its contribution to the magnetic moment would be very small—infinitesimally small, perhaps. Indeed, the magnetic moment of any circulating, orbiting or spinning charge is inversely proportional to the radius. Hence, if the radius of the *zbw* charge is of the order of α times the Compton radius, then its contribution to the magnetic moment should be of the order of 1/α. Oliver Consa (2018) took a bit of an engineering approach and calculated this contribution using an alternative interpretation of the ring electron model. He refers to it as the *Helical Electron Model*.[19] The basic assumptions are the following:

1. All of the electron's charge is concentrated in a single infinitesimal point, which is referred to as the center of charge, and which rotates at the speed of light around a point in space called the center of mass.
2. As it moves around the center of mass (CM), the center of charge (CC) follows a helical path.

These two hypotheses are best illustrated in Fig. 3 and 4 of his paper, which we copy below so as to illustrate the main ideas.

Figure 1: Consa's Helical Electron Model (toroidal versus poloidal currents)

[19] Oliver Consa, *Helical Solenoid Model of the Electron*, in: *Progress in Physics*, Volume 14, Issue 2 (April 2018). See: http://www.ptep-online.com/2018/PP-53-06.PDF.

We find the argument very interesting but somewhat contradictory.[20] Consa assumes the *zbw* charge moves around the center at the speed of light. However, he forgets that leaves no room for any motion in any other direction: lightspeed is lightspeed. Things cannot move any faster. Hence, we feel Consa falls in the same trap as mainstream physicists: he assumes a pointlike charge that has no dimension whatsoever. The calculations are interesting though, because it is easy to think of the toroidal current as a spherical charge that is just spinning around its own axis. As such, Consa's model should be mathematically equivalent to ours. To make a long story short, Consa obtains the following result:

$$\frac{1}{2}\left(\frac{r \cdot \mathrm{N}}{\mathrm{R}}\right)^2 = \frac{\alpha}{2\pi}$$

The N, R and *r* in this equality are the number of loops (N), the diameter of the ring (R) and its thickness (*r*) respectively. Hence, Consa's result is great: he gets Schwinger's factor (α/2π) from a very classical calculation. We just need to carefully think about what means what here. We assume the *r*/*R* ratio to be equal to equal to α, i.e. the ratio of the *Thomson* and *Compton* radius of an electron. Substituting this value, we get the following hypothetical formula:

$$\frac{1}{2}(\alpha \cdot \mathrm{N})^2 = \frac{\alpha}{2\pi} \Leftrightarrow \mathrm{N} = \frac{1}{\sqrt{\alpha\pi}} \approx 6.6$$

We find it hard to make sense of this result. One would expect the *zbw* charge to turn around like once or twice—some *integral* number: not some number that incorporates π or 1/α or some square root of an irrational number. At the same time, we feel Consa is doing something right here because we do *not* get a totally non-sensical number here: the *order of magnitude* is right on. Hence, we should probably leave this question open as for now by quoting Feynman when doing the same kind of back-of-the-envelope calculations on the Bohr radius of an atom:[21]:

> "We need not trust our answer to within factors like 2, π, etc. We have not even defined *a* very precisely."

To be precise, we think that Consa – as a result of mathematical idealizations – might have gotten a 1/√απ factor wrong.[22] But perhaps not. The right order of magnitude is there, and we feel it should explain previously unexplained quantum-mechanical phenomena such as the Lamb shift in the hydrogen spectrum.

Spin and orbital angular momentum (2)

Let us approach the issue from another angle by doing another classical calculation. We can, effectively, calculate the *orbital* angular momentum of the *zbw* charge rotating around the center of the ring current using the angular mass formula for a hoop: I = m·r^2. If we use the *effective* mass of the *zbw*

[20] For a more detailed analysis of Consa's argument, see our paper on it (https://vixra.org/abs/2001.0264).

[21] See: https://www.feynmanlectures.caltech.edu/III_02.html#Ch2-S4.

[22] This may or may not be related to the two very different assumptions: Consa's assumption of a dimensionless charge in a helical motion and our assumption of a *zbw* charge with an actual radius and some (very tiny) mass are, obviously, very different.

charge, we get what mainstream physicists will want to see—an angular momentum that is equal to ħ/2. We write[23]:

$$\mathrm{L} = \mathrm{I}\omega = \mathrm{m}_\gamma a^2 \frac{c}{a} = \frac{\mathrm{m_e} rc}{2} = \frac{\mathrm{m_e}\hbar c}{2\mathrm{m_e} c} = \frac{\hbar}{2}$$

Hurrah! The electron comes out of as a spin-1/2 particle! Personally, we are not so excited. It's nice we see some kind of bridge with the mainstream interpretation of quantum physics, but we actually do *not* think the very general distinction between bosons and fermions (the distinction between spin-1/2 and spin-1 particles) is useful. [24] So we will happily cheer along but we are more interested in a related but more essential question: how should we calculate the other spin number—the *spin* of our *zbw* charge, which we'll denote as S?

We made an effort in the previous section but – to speak very frankly – we don't know. The spin around its own axis has a different symmetry axis and the formula for the angular mass of a sphere or spherical shell involves different form factors: I = (3/5)·m·r^2 or I = (2/3) ·m·r^2, to be precise. Hence, we should probably not try to add things here. In any case, we cannot directly measure angular momentum: the only thing we can measure is the magnetic moment, which is either up or down, and its magnitude is the above-mentioned CODATA value—not more or less but pretty precisely so. So what *can* we say, then? Not too much, probably. However, the following guesstimates may be useful.

1. The considerations and calculations in the previous section show the contribution of the *spin* angular momentum to the magnetic moment of the electron must be *very* small: the radius of the *zbw* charge is much smaller, and the *spin* velocity cannot be much faster than the *orbital* $v \approx 0.99942 \cdot c$ velocity, can it? Even if we equate the spin velocity to *c*, the contribution of spin to the measured magnetic moment of the electron will only be of the same order as the ratio between the classical electron radius and the Compton radius, which is equal to $\alpha \approx 0.0073$, which is less than 1%.

2. If we denote this contribution as ε, and if we equate the main contribution from the *orbital* angular momentum to the magnetic moment to 1, then we get the following matrix[25]:

zbw spin vs. ring current	clockwise (up)[26]	counterclockwise (down)
up	$1 + \varepsilon \approx 1$	$-1 + \varepsilon \approx -1$
down	$1 - \varepsilon \approx 1$	$-1 - \varepsilon \approx -1$

[23] The reader should not confuse the two symbols: I is angular mass or rotational inertia, while *I* denotes electric current. Note that we use the theoretical values for radius and velocity, i.e. the Compton radius and the speed of light.

[24] The $\mathrm{L} = \mathrm{m} \cdot v \cdot r = \frac{\hbar}{2\pi+\alpha}$ formula we derived must shock mainstream physicists. It does not only violate conventional wisdom – angular momentum should come in *exact* units of ħ or ħ/2, shouldn't it? – but it also challenges the assumption of an electron being a spin-1/2 particle. As for the latter objection, we are afraid we have never come across a decent explanation of what this magical spin-1/2 property actually means—and then we mean an explanation in terms of plain common-sense physics. Not in terms of theoretical boson-fermion distinctions, for which we see neither empirical evidence nor theoretical need.

[25] Wikipedia offers a confusing but – as far as we can see – also quite consistent explanation for the addition of spin and orbital angular momenta. See: https://en.wikipedia.org/wiki/Vector_model_of_the_atom.

[26] What is clockwise or counterclockwise depends on your reference frame, but that is the same for defining up or down. If we look from the opposite direction, both up and down as well as clockwise as well counterclockwise will swap their definition. Hence, the reference frame doesn't matter here. The same reasoning applies to the definition of what's up or down in regard to the plane of the circulation of the *zbw* charge.

This matrix shows the electron – when doing a Stern-Gerlach experiment – should appear to be in two states: its magnetic moment will be either *up* (+1) or *down* (−1). However, a finer measurement might reveal a *split* of these two states. The split will be very *fine*—in line with the secondary structure of hydrogen spectrum lines, we would guess.

We am not aware of any measurements having been made here. In fact, actual Stern-Gerlach experiments are done with electrically neutral particles, such as potassium atoms[27] or, in the original experiment, silver atoms. This is because any electric charge in the magnetic field in the Stern-Gerlach apparatus would be subject to a Lorentz force which would be much larger than the force resulting from the magnetic moment.

In 1997, H. Batelaan, T. J. Gay, and J. J. Schwendiman wrote an intriguing *letter* to the *Physical Review* journal on how the Stern-Gerlach experiment could be modified to also split an electron beam based on the magnetic moment being up or down.[28] We are not aware of any follow-up.

The lack of any follow-up on Stern-Gerlach splitting of electron beams is rather strange because this is a very testable prediction of the ring current electron model: would or would we not get a finer splitting of the two main spots where the electron should hit the detector after going through the magnetic field of a Stern-Gerlach apparatus? We think there should be such finer split, but let us first wait until Brillouin's experiment[29] is being carried out—so we're sure about the basics, at least!

[…]

We have been doing very difficult things so now is time, perhaps, to sit back a bit and engage in some philosophy. Let us first think about units and constants. We will then also say something about the Uncertainty Principle and, to conclude, about the essence of the electron model itself.

The fundamental units of physics

Indeed, all of the results above are very wonderful—too wonderful, perhaps.[30] We may relate them to a more philosophical question: what is *fundamental* in Nature? In other words, what are *first principles*, and what can be *derived* from them?

The Planck-Einstein relation tells us that Planck's constant (h) reflects a fundamental *cycle* in Nature—so that is *very* fundamental, indeed! We also consider the absolute speed of light (c) to be another fundamental *fact*. From these two, we get the idea of a force. Indeed, the physical dimension of Planck's constant is a force over some distance during some time ($F \cdot \Delta s \cdot \Delta t$). Hence, combining h and c, we could define a natural unit for the force, based on whatever natural unit we would want to choose for distance

[27] See, for example, the MIT's lab experiment for students: http://web.mit.edu/8.13/www/JLExperiments/JLExp18.pdf.

[28] Physical Review Letters, H. Batelaan, T. J. Gay, and J. J. Schwendiman, *Stern-Gerlach Effect for Electron Beams*, Vol. 79, 8 Dec 1997, number 23 (https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1031&context=physicsgay).

[29] The proposal of Batelaan, Gay and Schwendiman is based on a much older proposal of the French physicist Léon Brillouin (L. Brillouin, Proc. Natl. Acad. Sci. U.S.A. 14, 755, 1928).

[30] We sent this to two very distinguished physicists whose names we won't reveal out of respect. We will just mention that both have done highly relevant work in the area of measuring the (electric) charge radius of the proton. To their credit, both bothered to react. One reacted by saying he finds this 'interesting'. The other reacted in the same manner but added that (some of the calculations) looked a bit like 'numerology'. We, obviously, do not take the last comment very seriously. We believe our calculations are very *real*: no quantum-mechanical hocus-pocus here!

and time—say, the second for time and the light-second for distance, although smaller units would be much more convenient at the sub-atomic scale.[31]

As mentioned, the idea of a force combines two ideas: it acts on a charge, but the charge must have some *inertia* to a change in its state of motion. Otherwise, we get nonsense as we, hopefully, managed to demonstrate in our introduction to this paper.

The first idea – a force acting on a charge – may be used to define a natural unit for the charge which, in this case, is the electric charge.[32] The second idea would define a natural mass unit. For the first, it is quite obvious that the charge of an electron – which is nothing but the *zbw* charge inside – would be the right choice. For the second, we may briefly wonder whether we shouldn't consider the mass of the *zbw* charge, but the sensible answer here is obvious: we can only measure the mass of the electron and, hence, the mass of the electron should probably be our natural mass unit as well.

Apart from $\hbar$ and c, we also have the fine-structure constant α. How can we *define* it? The answer is: we cannot. We can only *measure* it from the anomalies and from the finer structure of the hydrogen spectrum. Both are related, even if these interrelations are, obviously, *not* self-evident.

Of course, while we can (probably) not *define* its numerical value, we may try to explain what it *is*. We have done so using our ring current model – not only for the electron itself but also for electron orbitals. These analyses lead us to characterize the fine-structure constant as a scaling constant but, as evident from our previous papers[33], it scales various physical dimensions—not only the dimensions in space!

The nature of the Uncertainty Principle

Is there any room for the Uncertainty Principle in our analysis? There is. We like to think of Planck's constant as a vector. Indeed, the force in the $F \cdot \Delta s \cdot \Delta t$ must have some direction. This direction may wander around. This is equivalent to saying that the plane of the ring current evolves in time which, of course, also means that the direction of the magnetic moment is changing all of the time. When a magnetic field is being applied, the electron snaps into place, so to speak.[34]

However, we have no idea of how *exactly* the angle of the plane of the *Zitterbewegung* or rotary motion of the charge could change: we cannot think of some obvious *clue* here. If we could, we would not hesitate to further develop this paper. However, it is, for us, not a priority to develop some answer to this question. Why not? Because it doesn't matter: we do not need to *explain* anything here. About half

[31] The only requirement for a natural distance and time unit is that the speed of light as expressed in these units should equal unity: $c = 1$. Hence, our choice for such units will involve some idea of *scale*. In mathematical terms, these units would all be equivalent because they differ by a proportionality constant only. There is a natural constant relating various scales: the fine-structure constant. We will come back to this.

[32] We wrote about the idea of a strong charge in our previous papers as part of our calculations of the electromagnetic radius of a proton ($4\hbar/mc \approx 0.841$ fm). Indeed, something must explain the extraordinarily *small* radius and, likewise, the extraordinarily *large* mass of a proton (the radius is *inversely* proportional to the mass in the ring current model). We may, therefore, want to think of a fundamental oscillation of some other charge – a *strong* charge – to explain the extra mass. This idea would lead to a distinction between the idea of an electromagnetic mass and the idea of a strong mass. However, we are very reluctant to engage in such theory because we would like to think of other theoretical models here. We may, for example, want to think that the electromagnetic oscillation might have different *modes* or higher harmonics. We are inspired here by the fact that the ring current model is easily applicable to the heavier variant of the electron—the *muon*.

[33] See our paper on the meaning of the fine-structure constant (https://vixra.org/abs/1812.0273).

[34] We obviously also think of the Larmor precession as an actual or *real* precessional motion of the *zbw* charge.

of the electrons that are entering a Stern-Gerlach apparatus will have their spin *up*, more or less, and the other half will have it *down*. The magnetic field then, somehow, *snaps* them into place. Of course, the reader will object to such reasoning: there should be some inertia here too, isn't it?

We cannot say much to that, except the obvious: apparently, there is *no* inertia here. Why? We don't know. All we can say is that it is a direct consequence of the Planck-Einstein relation. The question is related to the next: what keeps the current going, and what keeps the charge in its orbit?

What keeps the charge in its orbit?

It is an obvious question: what keeps the ring current going? It is related to the other obvious questions: what keeps the *zbw* charge in its orbit, and why does the energy *not* radiate away? Here also, we can only provide exploratory or speculative answers. Most current ring or *Zitterbewegung* theorists – think of David Hestenes and others – think the ring current generates the magnetic field that keeps it going. As such, they compare it to a superconducting ring of current.

We like this comparison and then we do not. We like it because a superconducting ring of current also keeps going without radiating any energy away. However, we also note superconduction is being explained in a very different way in mainstream mechanics: the explanation involves *Bose* condensation and (Cooper) *pairs* of electrons. We are quite mystified by that. At the same time, we did seem to be able to offer common-sense explanations for quite a few quantum-mechanical mysteries now (the physical meaning of the wavefunction, the wavelike behavior and interference of electrons and photons, the anomalous magnetic moment, the proton radius, etcetera). Hence, we may be able to explain superconductivity in some easier way one day too!

However, we have a second objection: it would seem a superconducting ring can have any radius. In contrast, the electron has only one specific Compton radius, and there is nothing that keeps the charge in its orbit. We think of that puzzle as a real 'fine-tuning problem'. So far, we can only make sense of it by assuming our two-dimensional oscillator model[35] is, somehow, more fundamental than what I'll refer to as Hestenes' 'superconduction' model. We get our 'perpetuum mobile' – so to speak – directly from (i) accepting Einstein's mass-energy equivalence relation ($E = m \cdot c^2$) for what it is, (ii) interpreting c as the tangential velocity of the *zbw* charge[36] ($c = a \cdot \omega$), and (iii) the Planck-Einstein relation ($E = \hbar \cdot \omega$):

$$a = \frac{c}{\omega} = \frac{c\hbar}{mc^2} = \frac{\hbar}{mc} = \frac{\lambda_C}{2\pi} \approx 0.386159268 \ldots \text{ pm}$$

We admit it is still mysterious, but it is the best we've got. All the rest – most of the Standard Model, that is[37] – looks even more mysterious to us. It looks like a remake of the intellectual battle between Ptolemaic and Copernican models: both yield results, but one is significantly simpler than the other. History will decide which model wins. Until that day, we should just try to heed Wittgenstein's advice:

"*Wovon man nicht sprechen kann, darüber muß man schweigen.*"

Jean Louis Van Belle, 5 March 2020

[35] See: https://vixra.org/pdf/1905.0521v4.pdf.

[36] We also referred to the *zbw* charge as a naked charge: it has no properties except its charge. It has, therefore, zero rest mass and that is why it moves around at lightspeed: the slightest force on it will cause an infinite acceleration.

[37] We think of the Higgs field here, for example. In our model, a charge comes with a (tiny) mass. No need for hocus-pocus!