The ring current model for antimatter and other questions

Jean Louis Van Belle, 2 April 2020

Summary

Richard Feynman suggested anti-particles behave like they are traveling back in time. We think that is nonsense: in a ring current model, one distinguishes matter and anti-matter by the *direction* of travel of the charge inside. That is all. Using (or abusing) Minkowski's notation, we may say the spacetime signature of an electron (or an antiproton) is + – – – while that of a positron (or proton) would be + +++.

Indeed, in the ring current model of matter-particles, the magnetic moment alone does not allow one to distinguish between an electron with spin *up* and a positron with spin *down*. All we know is that the current that generates the magnetic moment must be different: one carries a negative charge, and the other carries a positive charge – and the *direction* of the *physical* current (the motion of the *zbw* charge) is opposite. The question then becomes: what distinguishes the positive and a negative *zbw* charge inside the *zbw* electron and positron? We suggest that the assumption of a two-level fractal structure, in which the *zbw* charge itself also spins, may provide a logical answer to that question.

The second topic of this paper are 'other questions' on the ring current model. Indeed, we all do have a number of philosophical or conceptual questions on the ring current model, which we thought we might, perhaps, insert in this paper – if only because we didn't quite know where to put them else.

Contents

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Introduction

The concept of a lightspeed circular current is at the core of our model of matter-particles. In this paper, we want to think about two inter-related questions: what's the model for antimatter, and what's the nature of the *Zitterbewegung* (zbw) charge inside?[1] As our thoughts are not very firm on this, the paper will come across as being highly speculative—and it surely is! However, as with previous papers, we hope it will generate some more thinking and discussion, which may or may not lead to an improved result in some distant or not so distant future. 😊

The second topic of this paper are 'other questions' on the ring current model. Indeed, we struggle with a limited but important number of questions on our model and, because we don't know quite where to put those, we've thought we might as well add them here—in a separate section which, to echo Feynman's dislike of philosophers (which we actually do *not* share), we've titled this: the ring current model and philosophers. 😊

Matter and antimatter ring currents

In previous papers, we wrote the magnetic moment of an electron as $\mu \approx 9.2847647043(28)\times10^{-24}$ J·T^{-1} (its *measured* value as published Committee on Data (CODATA) of the International Science Council) or as $\mu = q_e\hbar/2m$ (its theoretical value). We were actually a bit sloppy there: q_e is the *elementary* charge. It's the charge we associate with a proton or a *positron* – the latter being the electron's antimatter counterpart – and so it equal to *minus* the electron charge. We should, therefore, have put a minus sign everywhere. However, we were interesting in *magnitudes* only – and in particular the magnitude of the *anomalous* magnetic moment – and so we did not bother too much. It is now time to be more precise.

Consider a particular direction of the elementary current generating the magnetic moment. It is easy to see that the magnetic moment of an electron ($\mu = -q_e\hbar/2m$) and that of a positron ($\mu = +q_e\hbar/2m$) would be opposite. We may associate a particular direction of rotation with an angular frequency *vector* $\boldsymbol{\omega}$ which – depending on the direction of the current – will be up or down with regard to the plane of

[1] Erwin Schrödinger coined the term *Zitterbewegung* term while exploring solutions to Dirac's equation for a free electron. We refer to Oliver Consa (2018) for a brief historical overview of the development of the ring current model (https://vixra.org/abs/1809.0567). We must also assume the reader is somewhat familiar with our previous writings (https://vixra.org/author/jean_louis_van_belle). If not, the shortest introduction to it all is our new physics site (https://ideez.org/).

rotation.[2] We associate this with the spin property, which is also up or down.[3] We, therefore, have four possibilities[4]:

Matter-antimatter	**Spin up**	**Spin down**
Electron	$\mu_{-e} = -q_e\hbar/2m$	$\mu_{-e} = +q_e\hbar/2m$
Positron	$\mu_{+e} = +q_e\hbar/2m$	$\mu_{+e} = -q_e\hbar/2m$

This shows the ring current model also applies to antimatter. In fact, Richard Feynman suggested time reversal for anti-particles. We think that is nonsense: it is reversal of *direction*, obviously! Abusing Minkowski's notation, we may say the spacetime signature of an electron is a (+ – – –) while that of a positron would be (+ + + +).

The relevant question is this: what *exactly* distinguishes an electron with spin *up* and a positron with spin *down*? We cannot tell from the magnetic moment. Vice versa, the magnetic moment will be the same for an electron with spin *down* and a positron with spin *up*. So what makes an electron different from a positron then?

The obvious answer is this, of course: try to bring two electrons together, and then try to bring an electron and a positron together, and you will see two *very* different things happening. 😊 However, we are looking for some *intrinsic* property here. The answer is this, obviously: in the electron with spin *up*, we have the same current as in the positron with spin *down*, but it is because we have *an opposite charge* (negative instead of positive) *spinning in the opposite direction* (up instead of down, or right versus left—whatever you want to call it).

[…]

Are we kicking the can down the road here?

Yes and no. That depends on your answer to the next question: what is the difference between a negative and a positive *zbw* charge? There is an obvious answer to this question too, of course: one is positive and the other is negative! However, that does not satisfy us. If all is motion or spin, then we should, perhaps, think of some fractal structure here[5]: the *zbw* charge may also be spinning, and one direction of spin may be associated with a positive *zbw* charge, while the other would be associated with the opposite direction. However, I would think such answer *surely* amounts to kicking the can down the road!

[2] To determine what is up or down, one has to apply the ubiquitous right-hand rule.
[3] Richard Feynman suggested time reversal for anti-particles. We think that is nonsense: it is reversal of *direction*, of course. Abusing or adapting Minkowski's notation, we may say the spacetime signature of an electron is a (+ – – –), while that of a positron would be (+ +++).
[4] The use of the subscripts in the magnetic moment may be confusing, but shouldn't be: we use –e for an electron and +e for a positron. We do so to preserve the logic of denoting the (positive) elementary charge as q_e.
[5] The reader should note that we do *not necessarily* assume the fractal structure must be infinite. On the contrary, we think it may only go two levels down. These two levels would be associated with the *orbital* angular momentum of the *zbw* charge and the *spin* angular momentum of the charge itself.

Let us postpone the discussion for a while by trying to think of the *spatial* dimension of the *zbw* charge.

The spatial dimension of the *zbw* charge

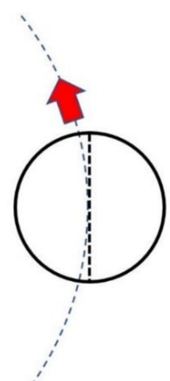
To explain the anomaly in the magnetic moment of an electron, we assumed that the *zbw* charge had some tiny but non-zero spatial dimension. We, therefore, distinguished an *effective* radius, which we denoted as r, from the theoretical radius, which is equal to the *Compton* radius $a = ħ/mc$. We made abstraction from the higher-order factors in the anomaly and only Schwinger's factor in the following calculation of r:

$$\left.\begin{array}{c}\frac{\mu_r}{\mu_a}=\frac{\frac{q_e vr}{2}}{\frac{q_e}{2m}\hbar}=\frac{v\cdot r}{c\cdot a}=\frac{\omega\cdot r^2}{\omega\cdot a^2}=\frac{r^2}{a^2}\\ \frac{\mu_r}{\mu_a}\approx 1+\frac{\alpha}{2\pi}\end{array}\right\}\Leftrightarrow r\approx\sqrt{1+\frac{\alpha}{2\pi}}\cdot a\approx 1.00058\cdot\frac{\hbar}{mc}$$

The reader should note this is a rather good approximation: using the CODATA value for μ_r (and for α, of course) and our theoretical value for μ_a ($-q_e ħ/2m$), the reader can check the μr/μa ratio is equal to about 99.99982445% of 1 + α/2π.[6] Hence, the accuracy is better than two parts in a million, which makes us think the higher-order factors may not be needed.[7] The only thing that is left to explain is this: why would the effective radius be *larger* than the theoretical one? In fact, the *effective* velocity must then also be *larger* than c. Indeed, the Planck-Einstein relation gives *one frequency* – not two – and we can, therefore, calculate the effective velocity v like this:

$$1=\frac{\omega}{\omega}=\frac{v/r}{c/a}\Leftrightarrow v=\frac{r}{a}\cdot c=\frac{\sqrt{1+\frac{\alpha}{2\pi}}\cdot a}{a}\cdot c=\sqrt{1+\frac{\alpha}{2\pi}}\cdot c\approx 1.00058\cdot c$$

We get the same ratio. How can the effective velocity be *larger* than c? It is related to the concept of the *effective center of charge*, which we can probably best understand by illustrating the (imagined) *physicality* of the situation—depicted below.



[6] The reader may wonder about the minus signs but can see the minus signs cancel each other in the ratio.
[7] The professional physicist will immediately note that the relative uncertainty in the CODATA value is *smaller* than that: 3×10^{-10}, to be precise. However, we are talking a *ratio* here, rather than the absolute value and, in any case, we should leave the work of calculating higher-order factors to the professionals anyway—if only because we have no understanding of mainstream mathematical toys (quantum field theory).

Indeed, if the *zbw* charge is whizzing around at the speed of light, and we think of it as a charged sphere or shell, then its effective *center of charge* will *not* coincide with its mathematical center (read: the center of the circle). Why not? Because the ratio between (1) the charge that is outside of the disk formed by the radius of its orbital motion and (2) the charge inside, will be slightly *larger* than 1/2. Indeed, the reader should carefully note the small triangular areas – two little *slices*, really – between the diameter line of the smaller circle (think of it as the *zbw* charge) and the larger circle (which represent the orbital of its *Zitterbewegung* or oscillatory motion).

We know the professional physicist will probably shake his or her head here and sigh: *you cannot possibly believe the illustration above might represent something real, right?*

We actually do. Why? We think it is a much easier and, therefore, *better* explanation than the mainstream explanation of the anomalous magnetic moment—especially because its history is somewhat dubious.[8]

Let us, therefore, examine this presumed spatial dimension of the *zbw* charge somewhat more in detail. The analysis above does *not* allow us to conclude that the radius or diameter of the *zbw* charge must be this or that value. The radius of the *zbw* charge and the difference between the effective and theoretical (Compton) radius of an electron – as calculated above – are very different. In fact, the latter must be some (small) fraction of the former. When doing some calculations, one immediately observes something very weird. The Thomson scattering radius is equal to this:

$$r_e = \alpha r_C = \alpha \frac{\hbar}{\mathrm{m_e} c} = \frac{\mathrm{q_e^2}}{4\pi\varepsilon_0 \hbar c} \frac{\hbar}{\mathrm{m_e} c} = \frac{\mathrm{q_e^2}}{4\pi\varepsilon_0 \mathrm{E_e}}$$

Now, if we would associate this with the radius of the *zbw* charge – which may or may not make sense – then we find that the *ratio* between the fine-structure constant (α) and the $\sqrt{1+\frac{\alpha}{2\pi}} \approx 1.00058$ factor is also (almost) equal to α. To be precise, we get this[9]:

$$\frac{\alpha}{\sqrt{1+\frac{\alpha}{2\pi}}} \approx \frac{0.007297\ldots}{1.00058\ldots} = 0.007293\ldots$$

Is this numerology? Maybe. The fine-structure constant is a very small number, and so we would get something similar with any number that has the same order of magnitude. Indeed, the calculation above amounts to this:

$$\frac{\alpha}{\sqrt{1+\frac{\alpha}{2\pi}}} \approx \alpha \Leftrightarrow \frac{\alpha}{\alpha\sqrt{1+\frac{\alpha}{2\pi}}} = \frac{\alpha}{\sqrt{\alpha^2+\frac{\alpha^3}{2\pi}}} \approx \frac{\alpha}{\sqrt{\alpha^2}} = \frac{\alpha}{\alpha} = 1$$

Hence, yes: the difference is the $\alpha^3/2\pi$ in the square root, and that's exceedingly small because of (1) the small value of α and (2) the square root. It may be a coincidence, of course, but because we have nothing else to work with, we would probably like to assume the *hard-core charge* inside of our electron

[8] See Oliver Consa, *Something is rotten in the state of QED*, 1 February 2020 (https://vixra.org/abs/2002.0011).

[9] We calculated this ratio using the CODATA point estimate of the fine-structure constant, but we do not show all of the digits. Indeed, we truncated the digits to show the difference: 0.007293… as opposed to α = 0.007297…

(or our positron) will involve a factor equal to α, which gives us a radius of the order of $\alpha\hbar/mc$.

This raises an interesting question: how do we know our *zbw* charge is pointlike? Perhaps it is a true *ring* of charge: a toroidal structure rather than a pointlike structure. That is a good question, but the answer to it may be remarkably boring: a relativistically correct analysis of the *charge distribution* that's associated with a spherical charge moving in a circle at the speed of light seems to how it may be equivalent to a toroidal ring of charge.

Relativistic charge densities

If we imagine our pointlike charge to have a radius, then it is only logical to assume it has some volume too. Feynman's classical calculations of the equally classical electron radius assume an electron is, effectively, some tiny *sphere* or *shell* of charge.[10] This gives our toroidal or disk-like electron[11] some *volume*. Now, the charge of a particle is an *invariant* scalar quantity. It does, therefore, *not* depend on the frame of reference. However, **the charge *density* of a charge distribution will vary in the same way as the relativistic mass of a particle**. To be precise, the charge density as calculated in the moving reference frame (ρ) will be related to the charge density in the inertial frame of reference (ρ_0) as follows[12]:

$$\rho = \frac{1}{\sqrt{1-v^2/c^2}} \cdot \rho_0$$

This effect is entirely due to the relativistic length contraction effect. It is an interesting calculation, so let us quickly go through it. From special relativity theory, we know that the dimensions that are *transverse to the motion* – you should, of course, think of the radius of our *zbw* charge here! – remain unchanged.[13] Hence, the area $A = A_0$ is the same in the inertial (*S*) as well as in the moving reference frame (*S'*). However, the length L will be *shorter*, and this relativistic length contraction will be given by the same Lorentz factor: $L = L_0/\gamma$.[14]

[10] See Feynman's *Lecture* on electromagnetic mass (https://www.feynmanlectures.caltech.edu/II_28.html). The only inconvenience is that – depending on the form factor that is used – Feynman ends up with a 1/2, 2/3 or – using another approach to the calculations – a 3/4 factor. So he only gets a *fraction* of the classical electron radius.

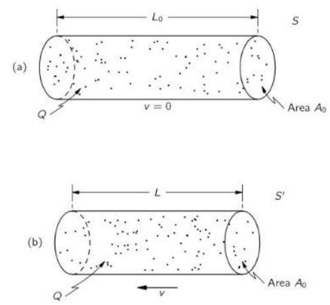
[11] For a discussion on the form factor in classical calculations of the anomalous magnetic moment (amm), see our discussion of the calculations of the amm of Oliver Consa (https://vixra.org/abs/2001.0264).

[12] See: Feynman's *Lectures*, *The Relativity of Magnetic and Electric Fields* (https://www.feynmanlectures.caltech.edu/II_13.html#Ch13-S6).

[13] We may remind the reader that Einstein – in his original 1905 article on special relativity – did actually introduce a distinction between the "longitudinal" and "transverse" mass of a moving charge. See p. 21 of the English translation of Einstein's article on special relativity, which can be downloaded from: http://hermes.ffn.ub.es/luisnavarro/nuevo_maletin/Einstein_1905_relativity.pdf. We feel the two concepts may be related to the equally relative distinction between the electrostatic and magnetic forces.

[14] Note we *divide* by the Lorentz factor here or, what amounts to the same, multiply with the *inverse* Lorentz factor.

Figure 1: The relativity of charge densities[15]



Substituting the *total* charge Q by q_e, we can write this:

$$q = \rho \cdot L \cdot A = \rho \cdot L \cdot A_0 = \rho_0 \cdot L_0 \cdot A_0 \Leftrightarrow \rho = \gamma \cdot \rho_0 = \frac{\rho_0}{\sqrt{1 - v^2/c^2}}$$

You may think the argument depends on a form factor: we are talking the volume of a cylindrical shape here, aren't we? Not really.[16] We could divide any volume (cylindrical, spherical or whatever other shape) into an infinite set of infinitesimally small cylindrical volumes and obtain the same result: the $\rho = \gamma \cdot \rho_0$ formula is also valid for the charge density as used in the general formula for an electric current, which is equal to: $I = \rho \cdot v \cdot A$. The velocity in this formula is just the velocity of the charge, and A is the same old cross-section of whatever 'wire' we would be looking at. Applying the relativistic formula above, and equating v to c, we can now calculate the current in terms of some *stationary* charge or – to be more precise – in terms of the *stationary charge distribution* ρ_0:

$$I = \rho \cdot v \cdot A = \frac{\rho_0}{\sqrt{1 - v^2/c^2}} \cdot v \cdot A$$

Hence, we get the same seemingly nonsensical division of zero by zero for $v = c$. How should we interpret this? We are not sure. We think it makes any meaningful discussion of the shape of the *stationary charge distribution* very difficult: a spherical charge moving in a circle at the speed of light is, therefore, probably equivalent to a toroidal ring of charge. As such, the discussions on such shape factor may distract from some more fundamental reality, which is and remains difficult to gauge or understand.

The effective mass of the *zbw* charge

The quintessential question is: how does a naked charge – in a circular current – acquire an effective mass? This is a deep mystery which we can only analyze mathematically, and even such mathematical analysis leaves us somewhat bewildered because we are applying equations to limiting situations. To be precise, we are calculating the $m_v = \gamma m_0$ product for γ (the Lorentz factor) going to 1 divided by 0 (*zero*),

[15] Source: Feynman's Lectures, Vol. II, Chapter 13, Fig. 13-11

[16] Note that the argument actually does *not* use the $V = \pi \cdot a^2 \cdot L$ formula, which is the formula one would use for the volume of a cylindrical shape. The argument only depends on the mathematical shape of the formula for electric current only ($\rho \cdot v \cdot A$) which, unsurprisingly, is the same as the $q = \rho \cdot L \cdot A$ formula: current is measured as charge per time unit, while a length may be expressed as the product of time and velocity. The reader may want to do a quick dimensional analysis of the equations to check the logic and appreciate the points made here.

while the *rest* mass m_0 is also supposed to be equal to zero. Indeed, with $m_0 \to 0$ and $v \to c$, we are dividing zero by zero in Einstein's relativistic mass formula:

$$m_v = \gamma \cdot m_0 = \frac{1}{\sqrt{1 - v^2/c^2}} \cdot m_0$$

We have not tried to solve this problem mathematically. Instead, we suggested a geometric solution, according to which the effective mass of our pointlike charge (which we denoted as $m_\gamma = m_{v=c}$) must be equal to 1/2 of the (rest) mass of the electron:

$$m_\gamma = m_{v=c} = \frac{m_e}{2}$$

We refer to our previous paper(s) for the detail.[17]

Let us return to the question we asked earlier: what makes a positive *zbw* charge a positive *zbw* charge, and what makes a negative one negative? The digressions above seemed to have distracted us, isn't it?

Maybe. Maybe not. We feel they are necessary when *speculating* about very difficult questions like this. They help us to get a feel for what might or might not be the case.

What makes antimatter antimatter?

We do not believe in *negative* space. Directions can be negative—in the sense that it is *opposite* to some other direction, but there is no such thing as negative space.

We also do not believe there is something like *negative* mass—just in case you think it might have something to do with that: any mass in our ring current or *Zitterbewegung* model is the *equivalent* mass of the energy in the oscillation, and that energy is positive. It's a textbook application of Wheeler's 'mass without mass' idea, and so we don't believe in *negative* energies—*not* the energy of an oscillation, that is. So what is left to differentiate a positive and a negative *zbw* charge, then?

We are not sure, but thinking of the electron as some kind of fractal structure is very appealing: the *zbw* charge may also be spinning around its own axis – we would expect such additional motion, right?[18] – and one direction of spin may be associated with a positive *zbw* charge, while the other would be associated with a negative charge.

You may think this sounds fantastical. We thought so too – initially, at least – but then we started to work on the atomic model – mapping what we found to the hydrogen spectrum and all that[19], and we found this hypothesis may make a lot of sense! The reasoning is like this: if we assume the *zbw* charge has spin of its own, then we can think of the magnetic moment of an electron consisting of the addition of the magnetic moment generated by the spinning *zbw* charge and the magnetic moment generated by the ring current.[20] The next question, then is, this: how should we *add* the two numbers? Following

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[17] See our *Metaphysics of Physics* paper, and especially annex 2 (https://vixra.org/abs/2001.0453).
[18] It is related to the ubiquitous distinction between *orbital* and *spin* angular momentum, both in classical as well as in quantum mechanics.
[19] See our paper with a *classical* or *realist* explanation of the Lamb shift (https://vixra.org/abs/2003.0644).
[20] 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.

considerations are relevant here:

1. 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 than the disk-like structure that we associate with the electron as a whole: instead of $I = (1/2)\cdot m\cdot r^2$, we should use the $I = (3/5)\cdot m\cdot r^2$ or $I = (2/3)\cdot m\cdot r^2$ formulas.

2. Apart from deciding on a form factor, we should also decide on this: what is *r* here? What is the *radius* of the *Zitterbewegung* charge that we think is *zittering* around at lightspeed? The *anomaly* of the magnetic moment of an electron suggests *r* is of the order of the classical electron radius, so that's a *fraction* (of the order of the fine-structure constant α, to be precise) of its *Compton* radius.

However, we noted this radius is a rather strange thing: the anomaly for the muon is about the same and, hence, the size of this *zbw* charge seems to be in the same relation with the (Compton) radius of a muon: *it shrinks along with it*.[21] Hence, we should probably *not* think of the *zbw* charge as some immutable *hard core* charge. Perhaps we should think in terms of some fractal structure here.

[…]

After reading the two points above, you should conclude this: we don't know much, do we? So what *can* we say then?

3. I think one conclusion – or *hypothesis*, I should say – should be fairly easy to agree with: the contribution of the *spin* angular momentum to the magnetic moment of the electron must be *very* small. Why? The radius of the *zbw* charge is much smaller, and the *spin* velocity can (also) not exceed the speed of light, can it? In short, 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%. We will denote the magnetic moment resulting from the *orbital* angular momentum as $\boldsymbol{l}_e$ (we hope this is not too confusing as a notation[22]), and the magnetic moment resulting from the *spin* angular momentum as $\boldsymbol{s}_e$, then we get the following matrix[23]:

***zbw* spin vs. ring current**	**clockwise (up)[24]**	**counterclockwise (down)**
up	$\boldsymbol{l}_e + \boldsymbol{s}_e \approx \boldsymbol{l}_e$	$-\boldsymbol{l}_e + \boldsymbol{s}_e \approx -\boldsymbol{l}_e$
down	$\boldsymbol{l}_e - \boldsymbol{s}_e \approx \boldsymbol{l}_e$	$-\boldsymbol{l}_e - \boldsymbol{s}_e \approx -\boldsymbol{l}_e$

[21] The anomalous magnetic moment of the muon is about the same when expressed as a *ratio* between the measurement and the theoretical value. Hence, our calculations of the size of the *zbw* charge are also *relative*. They must be, because the classical electron radius is actually *larger* than the radius of the muon.
[22] We previously reserved the *l* and *s* symbols for the *orbital* and *spin* angular momentum. Hence, it is not very logical to now use them for the magnetic moment, although the magnetic moment is – of course – related to it through the g-factor. However, we did not want to multiply the number of symbols as there are quite a lot already.
[23] 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. We, therefore, think we can also add the vectors that are associated with the magnetic moments, but we
[24] 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.

Note that we assume that $\boldsymbol{s}_{\mathrm{e}}$ will be a (small) fraction of $\boldsymbol{l}_{\mathrm{e}}$, which we may write as $\boldsymbol{s}_{\mathrm{e}} = \varepsilon\boldsymbol{l}_{\mathrm{e}}$. This shows that the magnetic moment of an electron in a magnetic field may take any of *four* values—two of which would be centered around $\boldsymbol{l}_{\mathrm{e}}$, and two of which would be centered around $-\boldsymbol{l}_{\mathrm{e}}$. The $\boldsymbol{l}_{\mathrm{e}}$ and $-\boldsymbol{l}_{\mathrm{e}}$ values correspond to the main *up* or *down* states of the electron. However, a finer measurement would, perhaps, reveal a very fine *split* of these two main states. As such, we may want to think of the orbital electron as a four-state system rather than a two-state system.

4. The angular momentum of the electron can then, of course, *couple* with the angular momentum of the proton, which must then – upon detailed examination – perhaps also come in *four* rather than two *states*. Hence, we can use the same table but, because a proton is much more massive and also because its angular momentum may or may not be different[25], the *spin* angular momentum may or may not be a *different* fraction of the orbital or total angular momentum. If we denote it by χ, we may write $\boldsymbol{s}_{\mathrm{p}} = \chi\boldsymbol{l}_{\mathrm{p}}$. We get the following matrix:

***zbw* spin vs. ring current**	**clockwise (up)[26]**	**counterclockwise (down)**
up	$\boldsymbol{l}_{\mathrm{p}} + \boldsymbol{s}_{\mathrm{p}} \approx \boldsymbol{l}_{\mathrm{p}}$	$-\boldsymbol{l}_{\mathrm{p}} + \boldsymbol{s}_{\mathrm{p}} \approx -\boldsymbol{l}_{\mathrm{p}}$
down	$\boldsymbol{l}_{\mathrm{p}} - \boldsymbol{s}_{\mathrm{p}} \approx \boldsymbol{l}_{\mathrm{p}}$	$-\boldsymbol{l}_{\mathrm{p}} - \boldsymbol{s}_{\mathrm{e}} \approx -\boldsymbol{l}_{\mathrm{p}}$

The magnetic moment of a proton is *much* smaller than that of an electron: the magnetic moment of an electron is of the order of -9.28×10^{-26} J/T, while the magnetic moment of a proton is of the order of 1.41×10^{-24} J/T. To be precise, the magnetic moment of an electron is about 658 times larger than that of a proton.[27]

Combining the four possible values for the electron with the four possible values for the electron, we get $4 \times 4 = 16$ different values centered around $2 \times 2 = 4$ *main* values ($\pm \boldsymbol{l}_{\mathrm{e}} \pm \boldsymbol{l}_{\mathrm{p}}$) which, in turn, are centered around $+\boldsymbol{l}_{\mathrm{e}}$ and $-\boldsymbol{l}_{\mathrm{e}}$ because of the relatively large value of the magnetic moment of the electron as compared to that of the proton. We think these 16 values should offer sufficient *degrees of freedom*[28] to analyze whatever fine, finer or finest structure we get from experiments analyzing the full width and depth of the hydrogen spectrum. We, therefore, see no need to think of "interactions between vacuum energy fluctuations", "one-, two- or n$^{\text{th}}$ loop effects", influences of "virtual photons", "zero-point oscillations" or whatever other metaphysical concepts that have been invented since World War II.[29]

[25] For our proton model, we refer to one of our recent papers (https://vixra.org/abs/2003.0144).
[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.
[27] We use the CODATA values for the calculation here.
[28] We have not less than 4×4 combinations here but the so-called selection rules (see: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/hydazi.html#c3) probably imply some combinations are not possible. Because of lack of time (we are not academics so we do have another day job), we have not managed to refine our research here.
[29] A fellow amateur physicist refers to mainstream physics as "cargo-cult science". We must admit we think that expression reflects the current situation rather well—with the emphasis on *cargo* and on *cult*, of course! The funny

5. In fact, it is total *overkill*, isn't it? We do not need 16 values: *four*, in some combination with the sub-shell number, will do. That's easy enough: *because the magnetic moment of a proton is so small in comparison with that of an electron, there may be no need to distinguish between the proton's orbital and spin angular momentum!* Hence, we may reduce the *four* spin states of the proton to *two* only—for practical (read: *measurement*) purposes, and that should solve the matter, doesn't it?

Well… No. We still have 8 hyperfine lines per energy level, rather than four. We only need four. Our conclusion may, therefore, be this: the electron is, perhaps, a true two-state system. It is obvious that, from a mathematical point of view, the *zbw* charge may spin in *two* possible directions. However, the fact that we only have *four* fine or hyperfine spectral levels for each energy level (or each subshell, we should say[30]) may imply that the sign of $\boldsymbol{s}_\mathbf{e}$ follows the sign of $\boldsymbol{l}_\mathbf{e}$. Hence, instead of $\pm\boldsymbol{l}_\mathbf{e} \pm \boldsymbol{s}_\mathbf{e}$ (*four* possibilities), we'd have only *two*, say $\pm(\boldsymbol{l}_\mathbf{e} + \boldsymbol{s}_\mathbf{e})$ or $\pm(\boldsymbol{l}_\mathbf{e} - \boldsymbol{s}_\mathbf{e})$.

What about Dirac's idea that, in a good model, any *mathematical* possibility should also correspond to some *physical* reality? This is how the positron was first predicted (by Dirac) and then, subsequently, *discovered* (by Carl D. Anderson).[31]

Well… That's exactly the point that we are trying to make here: a particle that has a charge going around in the same direction as an electron (here we are talking the *orbital* angular momentum of the particle as a whole) but with the elementary charge spinning around its own axis (here we are talking the *spin* orbital momentum of the *zbw* core charge) in the opposite direction (opposite to whatever the direction is in in the electron) is, perhaps, not an electron but a positron! Two of the mathematical possibilities in the four cells of our matrix would, therefore, not apply to the electron but to the positron!

[…]

Let me, to add to the above, also elaborate a bit what we said about the muon. The anomalous magnetic moment of a muon is, effectively, almost the same as that of an electron. Indeed, the CODATA values for the magnetic moment of an electron and a muon respectively are this[32]:

$$a_e = 1.00115965218128(18)$$

$$a_\mu = 1.00116592089(63)$$

This tells us that the radius of the *zbw* charge seems to shrink with the size of the particle ! Indeed, the classical electron radius is about 2.8 *femto*meter, so that's about 1.5 time *larger* than the (Compton) radius of a muon (about 1.87 fm). Hence, if the *zbw* charge inside a muon would be as large as, presumably, the radius of the *zbw* charge inside an electron, it would not fit in! And, if it did, we would get a *much* larger value for the anomaly: the difference between the effective and theoretical Compton

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thing is that it is a term which was, apparently, coined by Richard Feynman himself! See: http://calteches.library.caltech.edu/51/2/CargoCult.htm.

[30] Even this expression does not seem to be exact: for the main n = 1 energy level, we have two sub-lines. For the n = 2 level, we have two subshells, and each subshell has two *finer* lines – defined by the up or down spin of the *electron* – which are then divided in two *hyperfine* lines – which are defined by the up or down spin of the *proton*.

[31] Dirac first suggested a positron in 1928 and, in 1932, Carl D. Anderson eventually identified a positron in the pictures of the *debris* of gamma-rays entering his cloud chamber.

[32] It is confusing to use the symbol a to denote the anomaly: we are, indeed, *not* talking about the radius but about the anomaly here! However, we are just following the CODATA convention here.

radius would be *huge*, indeed!

In our paper(s) on the proton, we show we can apply the same reasoning to the proton, which is even smaller (only 0.83-0.84 fm, so that's another 2.22 times *smaller*).[33]

So, yes, the spatial dimensions (read: the *size*) of the *zbw* charge does seem to shrink as per the size of the larger particle. The idea of a fractal structure, therefore, makes sense, and the difference between a positive and a negative charge may be in the positive/negative direction of the spin of the *zbw* charge.

It sounds like a (very) shaky assumption and, yes, it feels very much like kicking the can down the road—to me too! Please let me know what you'd be thinking of. Something *not* involving (other) hocus-pocus, *please*? 😊

Now that we're talking assumptions and possible agendas for future research, I should, perhaps, also share some other thoughts on what these ring current models can and, perhaps, cannot do.

The ring current model and philosophers

As part of his presentation on (special) relativity theory, Richard Feynman famously criticizes philosophers for their (apparent) lack of depth when studying physics:

> "These philosophers are always with us, struggling in the periphery to try to tell us something, but they never really understand the subtleties and depths of the problem. […] One will find few philosophers who will calmly state that it is self-evident that if light goes 186,000 mi/sec inside a car, and the car is going 100,000 mi/sec, that the light also goes 186,000 mi/sec past an observer on the ground. That is a shocking fact to them; the very ones who claim it is obvious find, when you give them a specific fact, that it is not obvious."[34]

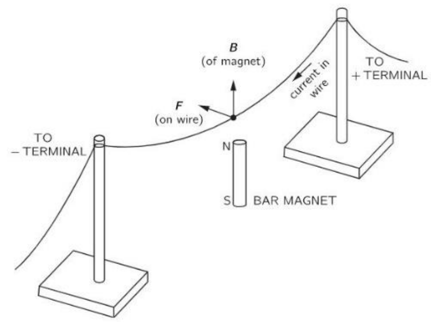
I love and hate Feynman's *Lectures*. I love them because they gave me all of the tools I now use to construct what I refer to as my 'basic version of truth' in regard to physics: *physics we can believe in*, as I sometimes jokingly say to friends. But I also hate them because Feynman's lectures on quantum mechanics also very cleverly introduce all of the unhelpful myths and half-truths that have hampered my search. What sentiment prevails? Sympathy, of course! In Zen, one may criticize the Master, but one should always remain kind and grateful to him. And statements like the one are very true.

I myself am constantly asking myself: is this ring current model *true*? It surely is very subtle: let no one give you the impression it is easy and self-evident. It is not. Simply stating it is "Nature's most fundamental superconducting current loop", for example, is hugely misleading, I think.[35] Various authors couch that statement in wonderful equations, and Hestenes even invented a new algebra for it (spacetime algebra[36]) but the reasoning behind it can often be summarized like this:

> A current in a wire is associated with a magnetic force (see the illustration from Feynman's

[33] To calculate the proton radius, one must take into account a very different angular momentum, it seems. We refer the reader to the Matter page of our physics site for a quick overview (https://ideez.org/matter/).
[34] https://www.feynmanlectures.caltech.edu/I_16.html.
[35] I am referring to Hestenes' own summary of his interpretation of the *Zitterbewegung* model here, as stated in an email he sent me about a year ago, in kind reply to a question I had sent him.
[36] See http://geocalc.clas.asu.edu/ and/or http://geocalc.clas.asu.edu/pdf/SpacetimePhysics.pdf.

Lectures below). Now, think of what happens if we'd have a current in a loop instead of a wire. We'd have a centripetal force, right?



Well… No. Two parallel wires with *opposite* currents (which is what you get when you make a loop out of that straight wire) will *repel* rather than attract each other. In addition, the law at work here is magnetism: the assumption is that the wires themselves are *electrically neutral*. So we have electrons moving in them – imagine them as electrons hopping from one temporary space to another but, importantly, *without changing the balance between positive and negative charges*, so we do *not* have any *net* electric *charge*. There is, therefore, no (electrostatic) repulsive force *between the electrons*. If there would be, that force would be enormous, because the magnitude of the electric force is *c* times *larger* than that of the magnetic force.

OK. We should correct ourselves here. The electric *field* strength is *c* times larger than the magnetic *field* strength ($B = E/c$), and the magnetic *force* itself is given not only by the (magnetic) field strength but also by the velocity of the charge. Remember Lorentz' law:

$$\mathbf{F} = q\cdot(\mathbf{E} + \boldsymbol{v}\times\mathbf{B}) = \mathbf{F}_E + \mathbf{F}_B = q\cdot(\mathbf{E} + \boldsymbol{v}\times\mathbf{B}) = q\cdot\mathbf{E} + q\cdot\boldsymbol{v}\times\mathbf{B}$$

So, yes, the magnitude of the *force* will be given by the *product* of the velocity and the magnetic field strength, and the electric and magnetic force will, effectively, be equally strong if the velocity of the charge is equal to *c*, which is what we assume to be the case in our ring current models[37]:

$$|\mathbf{F_B}| = F_B = qvB = qvE/c = qE \text{ for } v = c$$

[37] Needless to say, the reader should distinguish vector from scalar notion here: the magnetic and electric force are and will always remain perpendicular one to another. We should, perhaps add another note here. Some seem to think the $B = E/c$ relation might imply the magnetic force becomes more important at shorter distances. The idea is this: the *physical* dimension of the magnetic field is that of the electric field multiplied by *s*/*m*. Thinking of smaller distance scales is easy, so what if we would switch to the $\hbar/mc$ scale or something similarly small? The answer is: absolutely nothing. You're not changing anything physical here. Think of it like this: you will change the *numerical* value of *c* by changing the distance unit, but then you will also change *numerical* value of the velocity in the $\mathbf{F}_B = q\cdot\boldsymbol{v}\times\mathbf{B}$ formula. The two effects, therefore, cancel out. I am stating this quite explicitly because one of my friends thought there is no need to assume a strong(er) force inside of the muon or the proton arguing "*Zitterbewegung* current loops generated by elementary charges with smaller radius will have higher potential at their surface." He was obviously referring to the magnetic potential, but I am not sure why he thought this observation would explain the different mass of an electron and a muon (or a proton—for which we have the added complication of an angular momentum that seems to be *four* times that of the electron and the muon).

Hence, what we can say, *at best*, is that the electric and magnetic force between two *like* charges moving *parallel* to each other – both moving at the speed of light – will balance each other out. Hence, it should not be difficult to keep them together in a beam, for example.[38] However, two *like* charges moving in opposite directions vis-á-vis each other should still repel each other, with *twice* the force, actually! Hence, the question of what keeps them together – the centripetal force we have been trying to model, that is – remains *very* relevant.

Now that we're here – talking about *not-so-obvious* aspects of the ring current model – you should also note that Maxwell's laws seem to apply only selectively to our ring current: the orbiting charge should not only produce a magnetic field but probably also radiation – in light of the velocity, we're actually talking *synchrotron radiation* here![39] So it doesn't do that: it can't, obviously—otherwise we wouldn't be having the kind of perpetuum mobile that we think we are having here.

So, yes, there are a lot of questions—both philosophical as well as technical.

Conclusions: the research agenda ahead

What is that we were trying to say above? We wanted to say things are *not* as simple as they seem to be. Dr. Alex Burinskii's warning to me – when I contacted him around the same time as Dr. David Hestenes – still rings very true:

> "I know many people who considered the electron as a toroidal photon[40] and do it up to now. I also started from this model about 1969 and published an article in JETP in 1974 on it: "Microgeons with spin". Editor E. Lifschitz prohibited me then to write there about *Zitterbewegung* [because of ideological reasons[41]], but there is a remnant on this notion. There was also this key problem: what keeps [the pointlike charge] in its circular orbit?"[42]

He noted that this fundamental flaw was (and still is) the main reason why had abandoned the simple *Zitterbewegung* model in favor of the much more sophisticated Kerr-Newman approaches to the (possible) geometry of an electron.

I don't want to make the move he made because of the rather daunting math involved in Kerr-Newman geometries: it makes me feel there must be simpler answers, such as the assumption the motion is

[38] We found an interesting paper which clarifies this remarkable but obvious point: Oleg D. Jefimenko, 1998, On the Experimental Proofs of Relativistic Length Contraction and Time Dilation, Z. Naturforsch. 53a, 977-982 (https://www.degruyter.com/downloadpdf/j/zna.1998.53.issue-12/zna-1998-1208/zna1998-1208.pdf). We don't think all of the text makes sense, but a lot sure does!

[39] We could refer you to Wikipedia or some other article but we actually like our own treatment of the matter, which uses Feynman's text as a base: https://readingfeynman.org/2014/07/19/radiation-and-relativity/.

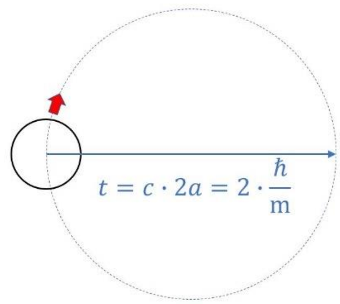
[40] This is Dr. Burinskii's terminology: it does refer to the *Zitterbewegung* electron: a pointlike charge with no mass in an oscillatory motion – orbiting at the speed of light around some center.

[41] This refers to perceived censorship from the part of Dr. Burinskii. In fact, some of what he wrote me strongly suggests some of his writings have, effectively, been suppressed because – when everything is said and done – they do fundamentally question – directly or indirectly – some key assumptions of the mainstream interpretation of quantum mechanics.

[42] Email from Dr. Burinskii to the author dated 22 December 2018.

really that of a two-dimensional oscillation in space and in time. But, *please*, you should not think things are simple. They are *not*.

Of course, you might think I am 'over-thinking' the model here. You may, for example, say that our remarks on a possible electrostatic *influence* of our charge on itself[43] may not be valid, because any such influence cannot travel fast enough to arrive on time, so to speak. It can only travel at the speed of light, and the time that it takes for our *zbw* charge to get to the other side of the ring is $\pi/2 \approx 1.57$ times the time it would take for the electrostatic repulsive effect to reach the same point.[44] Hence, by the time our charge is there, the *effect* of the electrostatic field in the electrostatic field is already gone.



Right. I am personally *not* doubting our model: I am just saying it is *not* as obvious as you may think it is. The use of Maxwell's laws in this situation is *not* self-evident. That's all I wanted to alert you to.

I should also alert you to something else. The illustration above assumes some sphere or some disc orbiting around: relativity theory tells us its *lateral* or *longitudinal* length – the length in the direction of motion, that is – will shorten to zero. So that should trigger some rather obvious questions in regard to our geometric explanation of the anomaly. Again, we're *not* doubting our model: we're just telling you to think it all through for yourself!

My last critical remark on our own model is the most fundamental of all: even if we think our photon, electron and proton model are as good as they can possibly get, we still need to use them to elegantly explain what needs to be explained: diffraction and interference of matter-particles (and photons)—*even if they are going one-by-one through the slit(s)*.

Indeed, we have repeatedly *said* that we *think* that the hybrid description that is implicit in the ring current model *should* provide for an elegant and consistent description of diffraction and interference patterns when forcing particles through single or double slits. Why? Because we can easily see that the wavefunction now reflects the oscillatory motion of the charge (or, in case of the photon, the electromagnetic *point* oscillation).[45] However, none of our papers have actually *given* such elegant and

[43] In case you doubt what we're talking about, or couldn't quite follow the preceding argument, this is really what we're talking about here: the electrostatic *repulsive* force that may or may not be present in our electron because of a charge that may or may not be distributed over the whole ring.

[44] The charge traveling at lightspeed following the orbital trajectory will need a time that is equal to $c \cdot 2\pi a/2 = c \cdot \pi a = \pi\hbar/\mathrm{m}$. In contrast, traveling along the diameter line only takes a time that is equal to $c \cdot 2a = 2\hbar/\mathrm{m}$.

[45] See, for example, our manuscript on a realist interpretation of quantum physics (https://vixra.org/abs/1901.0105).

consistent description: we were just too focused on getting the *basics* of the model right, which we think we have done now—more or less, at least!

You may wonder: why should that be so difficult? We offer some thoughts on that in the Annex to this paper: when the electron (or any of the particles we explain in terms of a ring current) starts moving, its geometry becomes quite complicated, and the question of what interacts with what exactly even more so!

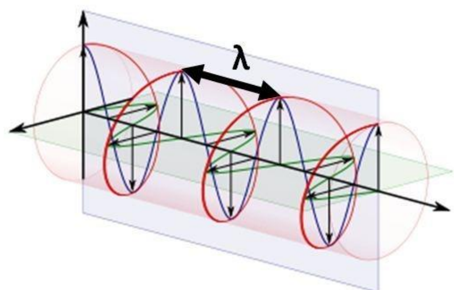
Hence, I feel I am only at the beginning of the journey !

Jean Louis Van Belle, 2 April 2020

Annex: Wavelengths, velocities and linear momentum[46]

We mentioned that we invested a lot in our electron and proton model because we believe the hybrid description of the ring current model should provide for a concise and consistent description of diffraction and interference patterns when forcing particles through single or double slits—*even if they are going through them one-by-one*. Why? Because we can now interpret the wavefunction as the oscillatory motion of the charge itself (or, in case of the photon, as an electromagnetic *point* oscillation) and we, therefore, can analyze it as some *physical* wave going through the slit(s).

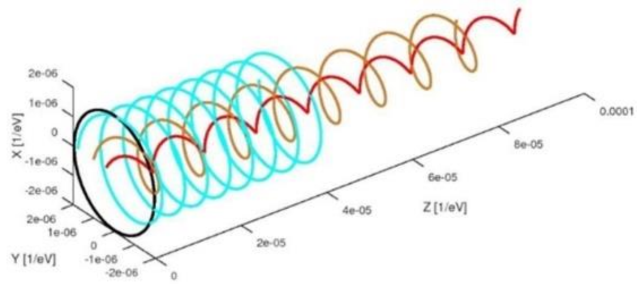
However, none of our papers have actually *given* such concise and consistent description: we were just too focused on getting the *basics* of the model right. Hence, it is about time we try to use them to explain what needs to be explained: diffraction and interference. In our manuscript[47], we presented this rather simplistic *Archimedes screw* illustration of how the *zbw* charge might actually move through space when the electron *as a whole* acquires some (non-relativistic) velocity *v*.



So is this a moving electron, *really*? Probably not: we see no reason why the *plane* of the oscillation – the plane of *rotation* of the pointlike charge, that is – should be perpendicular to the direction of propagation of the electron as a whole. On the contrary, we think there is every reason to believe the plane of oscillation moves about itself – in some kind of random motion – unless an external electromagnetic field snaps it into place, which may be either *up* or *down*, depending on where the magnetic moment was pointing when the electron – a magnetic dipole because of the current inside – entered the external field.

The illustration is useful to help us in understanding what may or may not be happening to the radius of the oscillation ($a = ħ/mc$) and the λ wavelength in the illustration above, which is like the distance between two crests or two troughs of the wave.[48] Indeed, we should briefly present a rather particular geometric property of the *Zitterbewegung* (*zbw*) motion: the $a = ħ/mc$ radius – the Compton radius of our electron – must decrease as the (classical) velocity of our electron increases. The idea is visualized in the illustration below (for which credit goes to an Italian group of *zbw* theorists[49]):

[46] A lot of the material in this Annex was copied from our manuscript: *The Emperor Has No Clothes: A Realist Interpretation of Quantum Mechanics* (https://vixra.org/abs/1901.0105).
[47] See the reference above.
[48] Because it is a wave in two dimensions, we cannot really say there are crests or troughs, but the terminology might help you with the interpretation of the geometry here.
[49] Vassallo, G., Di Tommaso, A. O., and Celani, F, *The Zitterbewegung interpretation of quantum mechanics as theoretical framework for ultra-dense deuterium and low energy nuclear reactions*, in: Journal of Condensed Matter Nuclear Science, 2017, Vol 24, pp. 32-41. Don't worry about the rather weird distance scale (1×10^{-6} eV^{-1}).



Zitterbewegung trajectories for different electron speeds: v/c = 0, 0.43, 0.86, 0.98

What happens here is quite easy to understand. If the tangential velocity remains equal to *c*, and the pointlike charge has to cover some horizontal distance as well, then the circumference of its rotational motion *must* decrease so it can cover the extra distance. But let us analyze it the way we should analyze it, and that's by using our formulas. Let us first think about our formula for the *zbw* radius *a*:

$$a = \frac{\hbar}{\mathrm{m}c} = \frac{\lambda_C}{2\pi}$$

The λ_C is the *Compton* wavelength, so that's the circumference of the circular motion.[50] How can it decrease? If the electron moves, it will have some kinetic energy, which we must add to the *rest energy*. Hence, the mass m in the denominator (m*c*) increases and, because *ħ* and *c* are physical constants, *a* must decrease.[51] How does that work with the frequency? The frequency is proportional to the energy ($\mathrm{E} = \hbar \cdot \omega = \mathrm{h} \cdot f = \mathrm{h/T}$) so the frequency – in whatever way you want to measure it – must also *increase*. The *cycle* time T, therefore, must *decrease*. We write:

$$\theta = \omega t = \frac{\mathrm{E}}{\hbar} t = \frac{\gamma \mathrm{E}_0}{\hbar} t = 2\pi \cdot \frac{\mathrm{t}}{\mathrm{T}}$$

So our Archimedes' screw gets stretched, so to speak. Let us think about what happens here. We get the following formula for our new λ wavelength:

$$\lambda = v \cdot \mathrm{T} = \frac{v}{f} = v \cdot \frac{\mathrm{h}}{\mathrm{E}} = v \cdot \frac{\mathrm{h}}{\mathrm{m}c^2} = \frac{v}{c} \cdot \frac{\mathrm{h}}{\mathrm{m}c} = \beta \cdot \lambda_C$$

Can the velocity go to *c*? In the limit, yes. Why? Because the rest mass of the *zbw* charge is zero. This is very interesting, because we can see that the circumference which describes the two-dimensional oscillation of the *zbw* charges seems to transform into some wavelength in the process! This relates the geometry of our *zbw* electron to the geometry of our photon model. However, we should not pay too much attention to this now.

Time and distance can be expressed in *inverse* energy units when using so-called *natural units* ($c = \hbar = 1$). We are not very fond of this because we think it does *not* necessarily clarify or simplify relations. Just note that $1{\times}10^{-9}$ eV^{-1} = 1 GeV^{-1} ≈ $0.1975{\times}10^{-15}$ m. As you can see, the *zbw* radius is of the order of $2{\times}10^{-6}$ eV^{-1} in the diagram, so that's about $0.4{\times}10^{-12}$ m, which is what we calculated: $a \approx 0.386{\times}10^{-12}$ m.

[50] Hence, the *C* subscript stands for the *C* of Compton, not for the speed of light (*c*).

[51] We advise the reader to always think about proportional ($y = kx$) and inversely proportional ($y = x/k$) relations in our *exposé*, because they are not always intuitive.

We have a classical velocity (v), so we should now relate the equally classical *linear* momentum of our particle to this geometry. Hence, we should now talk about the *de Broglie* wavelength, which we'll denote by using a separate subscript: $\lambda_p = h/p$.

Is it different from the λ wavelength we had already introduced? It is. We have *three* wavelengths now: the *Compton* wavelength λ_C (which is a circumference, actually), that weird horizontal distance λ, and the *de Broglie* wavelength λ_p. Can we make sense of that? We can. Let us first re-write the *de Broglie* wavelength in terms of the Compton wavelength ($\lambda_C = h/mc$), its (relative) velocity $\beta = v/c$, and the Lorentz factor γ:

$$\lambda_\mathrm{p} = \frac{h}{\mathrm{p}} = \frac{h}{\mathrm{m}v} = \frac{hc}{\mathrm{m}cv} = \frac{h}{\mathrm{m}c\beta} = \frac{\lambda_C}{\beta} = \frac{1}{\gamma\beta}\frac{h}{\mathrm{m}_0 c} = \frac{1}{\gamma\beta}2\pi a_0$$

It is a curious function, but it helps us to see what happens to the *de Broglie* wavelength as m and v both increase as our electron picks up some momentum $p = m \cdot v$. Its wavelength must actually *decrease* as its (linear) momentum goes from zero to some much larger value – possibly infinity as v goes to c – and the 1/γβ factor tells us *how* exactly. The graph below shows how the 1/γβ factor comes down from infinity (+∞) to zero as v goes from 0 to c or – what amounts to the same – if the relative velocity $\beta = v/c$ goes from 0 to 1. The 1/γ factor – so that's the inverse Lorentz factor) – is just a simple circular arc, while the 1/β function is just a regular inverse function ($y = 1/x$) over the domain $\beta = v/c$, which goes from 0 to 1 as v goes from 0 to c. Their product gives us the green curve which – as mentioned – comes down from +∞ to 0.

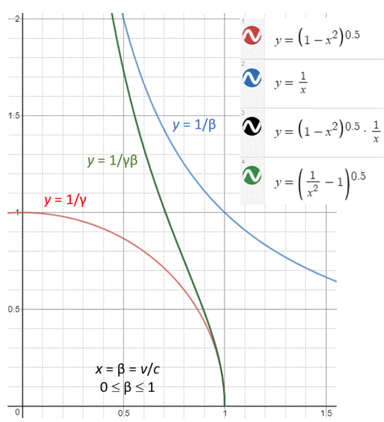


Figure 2: The 1/γ, 1/β and 1/γβ graphs

We may add two other results here:

1. The *de Broglie* wavelength will be equal to $\lambda_C = h/mc$ for $v = c$:

$$\lambda_\mathrm{p} = \frac{\mathrm{h}}{\mathrm{p}} = \frac{\mathrm{h}}{\mathrm{m}c}\cdot\frac{1}{\beta} = \lambda_C = \frac{\mathrm{h}}{\mathrm{m}c} \Leftrightarrow \beta = 1 \Leftrightarrow v = c$$

2. We can now relate both Compton as well as *de Broglie* wavelengths to our new wavelength $\lambda = \beta\cdot\lambda_C$ wavelength—which is that length between the crests or troughs of the wave.[52] We get the following two rather remarkable results:

$$\lambda_p \cdot \lambda = \lambda_p \cdot \beta \cdot \lambda_C = \frac{1}{\beta}\cdot\frac{h}{mc}\cdot\beta\cdot\frac{h}{mc} = \lambda_C^2$$

$$\frac{\lambda}{\lambda_p} = \frac{\beta\cdot\lambda_C}{\lambda} = \frac{p}{h}\cdot\frac{v}{c}\cdot\frac{h}{mc} = \frac{mv^2}{mc^2} = \beta^2$$

The product of the $\lambda = \beta\cdot\lambda_C$ wavelength and *de Broglie* wavelength is the square of the Compton wavelength, and their ratio is the square of the relative velocity $\beta = v/c$. – *always!* – and their ratio is equal to 1 – *always!* These two results are quite remarkable. Is there an easy geometric interpretation? There is if we use natural units. Equating *c* to 1 gives us natural distance and time units, and equating *h* to 1 then gives us a natural force unit—and, because of Newton's law, a natural mass unit as well. Why? Because Newton's $\boldsymbol{F} = m\cdot\boldsymbol{a}$ equation is relativistically correct: a force is that what gives some mass acceleration. Conversely, mass can be defined of the inertia to a change of its state of motion—because any change in motion involves a force and some acceleration. We write: $m = \mathbf{F}/\boldsymbol{a}$. If we re-define our distance, time and force units by equating *c* and *h* to 1, then the Compton wavelength (remember: it's a circumference, really) and the mass of our electron will have a simple inversely proportional relation:

$$\lambda_C = \frac{1}{\gamma m_0} = \frac{1}{m}$$

We get equally simple formulas for the *de Broglie* wavelength and our λ wavelength:

$$\lambda_p = \frac{1}{\beta\gamma m_0} = \frac{1}{\beta m}$$

$$\lambda = \beta\cdot\lambda_C = \frac{\beta}{\gamma m_0} = \frac{\beta}{m}$$

This is quite deep: we have three *lengths* here – defining all of the geometry of the model – and they all depend on the *rest* mass of our object and its relative velocity *only*. They are related through that equation we found above:

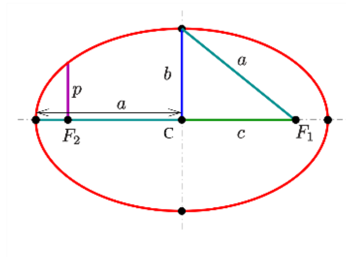
$$\lambda_p \cdot \lambda = \lambda_C^2 = \frac{1}{m^2}$$

This is nothing but the *latus rectum* formula for an ellipse. *What formula?* Relax. We didn't know it either. Just look at the illustration below.[53] The length of the chord – perpendicular to the major axis of an ellipse is referred to as the *latus rectum*. One half of that length is the actual *radius of curvature* of

[52] We should emphasize, once again, that our two-dimensional wave has no real crests or troughs: λ is just the distance between two points whose argument is the same—except for a phase factor equal to $n\cdot 2\pi$ (n = 1, 2,…).
[53] Source: Wikimedia Commons (By Ag2gaeh - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=57428275).

the osculating circles at the endpoints of the major axis.[54] We then have the usual distances along the major and minor axis (*a* and *b*). Now, one can show that the following formula has to be true:

$$a \cdot p = b^2$$



Hence, our three wavelengths obey the same formula. You may think this is interesting (or not), but you should ask: what's the relation with what we want to talk about?

You are right: the objective of the discussion above was just to give you a feel of the geometry of our electron as it starts moving about. As you can see, things aren't all that easy. Talking about some wave going through one slit (diffraction) or two slits (interference) sounds easy, but the nitty-gritty of it is *very* complicated.

We basically *assume* the electron – as an electromagnetic oscillation with some pointlike charge whirling around in it – does effectively go through the two slits at the same but how *exactly* it then interacts with the electrons of the material in which these slits were cut is a *very* complicated matter. We should *not* exclude, for example, that it may actually *not* be the same electron that goes in and comes out—and that's just for starters!

So, yes, we will likely be busy for years to come! 😊

[54] The endpoints are also known as the *vertices* of the ellipse. As for the concept of an osculating circles, that's the circle which, among all tangent circles at the given point, which approaches the curve most tightly. It was named *circulus osculans* – which is Latin for 'kissing circle' – by Gottfried Wilhelm Leibniz. You know him, right? Apart from being a polymath and a philosopher, he was also a great mathematician. In fact, he was the one who invented differential and integral calculus.