A classical interpretation of quantum electrodynamics (QED)

Jean Louis Van Belle, *Drs*, *MAEc*, *BAEc*, *BPhil*
31 December 2018

Email: jeanlouisvanbelle@outlook.com

Abstract: This paper summarizes our papers over the past years which – taken together – effectively amount to a classical interpretation of QED. Our very first paper started exploring a basic intuition: if QED is the theory of electrons and photons, and their interactions, then why is there no good model of what electrons and photons actually *are*? We have tried to address this perceived gap in the theory – further building on the *Zitterbewegung* model of an electron – ever since. We thought we should write one final paper to provide some history – acknowledgements, basically – and summarize the key principles of the interpretation.

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Introduction

The ideas and principles in this and previous papers[1] which, taken together, offer a comprehensive geometric interpretation of the wavefunction – and, therefore, of quantum electrodynamics[2] – are, obviously, very speculative. At the same time, much of what we write builds on well-established research. We note – in particular – what Hestenes refers to as the *Zitterbewegung* interpretation of quantum mechanics[3] and Burinskii's Dirac-Kerr-Newman electron[4] model. We just elaborated the consequences of these theories: while a *direct* verification of these models is not possible because of the very high frequency of the oscillatory motion (the *zbw* charge moves at the speed of light) and the very small amplitude (the Compton radius), logic tells us that the *form factor* that comes out of these models could be used in models that do *not* involve micro-motion at the speed of light.

In other words, we should be able to *indirectly* verify whether these models make sense or not by inserting the form factor in models that involve relativistically slow motion of an electron around a nucleus (atomic orbitals) or – to explain the anomalous magnetic moment – the motion of an electron in a Penning trap. Hence, we have been advocating what we argue is a *testable* interpretation.

The consideration of what we refer to as *the neglected form factor* in quantum mechanics led to other considerations: can we build a photon model? It turns out we can: Euler's wavefunction is a wonderfully *polyvalent*[5] mathematical object. Of course, we have had to deal with the usual objection: if the wavefunction of spin-1/2 particle has a 720-degree symmetry, how can one possible think of its geometry in three-dimensional space. We have answered this question in previous papers but include our explanation here again. Our answer to this question is, in effect, the core of the more comprehensive interpretation that is offered here.

Occam's Razor

If the ideas in this and our previous papers make sense, then we should acknowledge their origin. The input has been substantive and, therefore, deserves some elaboration.

The basics of our model is based on the idea of an oscillation in two dimensions. This naturally led us to the *Zitterbewegung* hypothesis. We contacted Dr. Giorgio Vassallo in this regard, who directed us also to Dr. Alex Burinskii. Both have been invaluable – not because they would want to be associated with any of our ideas – but because they gave us the benefit of the doubt in their occasional but consistent communications. Hence, we would like to thank them for reacting and encouraging us for at least *trying* to understand.

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[1] See: http://vixra.org/author/jean_louis_van_belle.

[2] We have *not* made any comments on the theoretical approach to other sectors of the Standard Model – although we noted the new interpretation that is offered might have repercussions.

[3] David Hestenes, *The Zitterbewegung Interpretation of Quantum Mechanics*, January 1990. We should also include a reference to the research of Francesco Celani, Giorgio Vassallo and Antonino Oscar Di Tommaso, who continue to explore the model.

[4] Alexander Burinskii, *The Dirac–Kerr–Newman electron*, 19 March 2008. Also see his *New Path to Unification of Gravity with Particle Physics*, 2016.

[5] Polyvalent is a Dutch word which means: having multiple values. In English it is multifunctional.

They made us realize that QED, as a theory, might be incomplete: it is all about electrons and photons, and the interactions between the two – but the theory lacks a good description of what electrons and photons actually *are*. Hence, all of the weirdness of Nature is now, somehow, in this weird description of the fields: perturbation theory, gauge theories, Feynman diagrams, quantum field theory, etcetera. This complexity in the mathematical framework does *not* match the intuition that, if the theory has a simple circle group structure[6], one should not be calculating a zillion integrals all over space over 891 4-loop Feynman diagrams to explain the magnetic moment of an electron in a Penning trap.[7] We feel validated because, in his latest communication, Dr. Burinskii wrote he takes our idea of trying to corroborate his Dirac-Kerr-Newman electron model by inserting it into models that involve some kind of slow orbital motion of the electron – as it does in the Penning trap – seriously.[8]

There are a few more professors who have, somehow, been responsive and, therefore, encouraging. We fondly recall that, back in 2015, Dr. Lloyd N. Trefethen from the Oxford Math Institute reacted to a blog article on ours[9] – in which we pointed out a potential flaw in one of Richard Feynman's arguments. It was on a totally unrelated topic – the rather mundane topic of electromagnetic shielding, to be precise – but his acknowledgement that Feynman's argument was, effectively, flawed and that he and his colleagues had solved the issue in 2014 only (Chapman, Hewett and Trefethen, *The Mathematics of the Faraday Cage*) was an eye-opener for me. Trefethen concluded his email as follows: "Most texts on physics and electromagnetism, weirdly, don't treat shielding at all, neither correctly nor incorrectly. This seems a real oddity of history given how important shielding is to technology." We were shocked: how is it possible that scientists, engineers and technicians alike, for almost 200 years,[10] work with formulas in this area (shielding) that are based on a flawed argument? This resulted in a firm determination to *not* take any formula for granted – even if they have been written by Richard Feynman ! – but re-visit their origin instead.[11] We might say this episode provided us with the guts to question orthodox quantum theory.

We have also been in touch with Dr. John P. Ralston, who wrote one of a very rare number of texts that, at the very least, *tries* to address some of the honest questions of amateur physicists and philosophers upfront. We were not convinced by his interpretation of quantum mechanics, but we loved the self-criticism of the profession: "Quantum mechanics is the only subject in physics where teachers traditionally present haywire axioms they don't really believe, and regularly violate in research." We exchanged some messages, but then concluded that our respective interpretations of the wavefunction

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[6] QED is an Abelian gauge theory with the symmetry group U(1). This sounds extremely complicated – and it is. However, it can be translated as: its mathematical structure is basically the same as that of classical electromagnetics.

[7] We refer to the latest theoretical explanation of the anomalous magnetic moment here: Stefano Laporta, *High-precision calculation of the 4-loop contribution to the electron g-2 in QED*, 10 July 2017, https://arxiv.org/abs/1704.06996.

[8] Prof. Dr. Burinskii, email communication, 29 December 2018 2.13 pm (Brussels time). To be precise, he just wrote us to say he is 'working on the magnetic moment'. We interpret this as saying he is looking at his model again to calculate the magnetic moment of the Dirac-Kerr-Newman electron so we will be in a position to show how the Kerr-Newman geometry – which we refer to as the (neglected) *form factor* in QED – might affect it. To be fully transparent, Dr. Burinskii made it clear his terse reactions do not amount to any endorsement or association of the ideas expressed in this and other papers. It only amounts to an admission our logic may have flaws but no fatal errors – not at first reading, at least.

[9] Jean Louis Van Belle, *The field from a grid*, 31 August 2015, https://readingfeynman.org/2015/08/.

[10] We should not be misunderstood here: the formulas – the conclusions – are fully *correct*, but the argument behind was, somehow, misconstrued. As Faraday performed his experiment with a metal *mesh* (instead of a metal *shell*) in 1836, we may say it took mankind 2014 – 1836 = 178 years to figure this out. In fact, the original experiments on Faraday's cage were done by Benjamin Franklin – back in 1755, so that is 263 years ago!

[11] We reached out to Dr. Trefethen and some of his colleagues again to solicit comments on our more recent papers, but we received no reply. Only Dr. André Weideman wrote us back saying that this was completely out of his field and that he would, therefore, not invest in it.

are very different and, hence, that we should not waste any electrons on trying to convince each other.[12]

In the same vein, we should mention some other seemingly random exchanges – such as those with the staff and fellow students when going through the MIT's edX course on quantum mechanics which – we admit – we did not fully complete because, while we don't mind calculations in general, we do mind *mindless* calculations.[13] We are also *very* grateful to our brother, Dr. Jean Paul Van Belle, for totally unrelated discussions on his key topic of research (which is information systems and artificial intelligence), which included discussions on Roger Penrose's books – mainly *The Emperor's New Mind* and *The Road to Reality*. These books made us think about a working title for a future popular book on physics: *The Emperor has no clothes: the sorry state of Quantum Physics*. We will go for another mountainbike or mountain-climbing adventure when this project is over.

Among other academics, we would like to single out Dr. Ines Urdaneta whose own independent research is very similar to ours. She has, therefore, provided much-needed moral support and external validation. We also warmly thank Jason Hise, whose wonderful animations of 720-degree symmetries did *not* convince us that electrons – as spin-1/2 particles actually have such symmetries – but whose communications stimulated our thinking on the subject-object relation in quantum mechanics.

Finally, we would like to thank all our friends and our family for keeping us sane. We would like to thank, in particular, our children – Hannah and Vincent – and our wife, Maria, for having given us the emotional, intellectual and financial space to pursue this intellectual adventure.

Let us now recap the core principles of our interpretation. We start with the mentioned issue of the 720-degree symmetries. We think these supposed symmetries are based on a mathematical convention only. We, therefore, think they do *not* reflect any reality. Let us briefly explain why.[14]

The double meaning of –1 (aka: –1 is a complex number)

Thomas Aquinas starts his *de Ente et Essentia* (on Being and Essence) quoting Aristotle: *quia parvus error in principio magnus est in fine*. A small error in the beginning can lead to great errors in the conclusions. This philosophical warning – combined with Occam's quest for mathematical parsimony – made us think about the mathematical framework of quantum mechanics: its rules explain reality, but no one understands them. Perhaps some small mistake has been made – early on – in the *interpretation* of the math. This has been a long quest – with little support along the way[15] – but we think we have found the small mistake – and we do believe it has led to some substantial misunderstandings – or, at the very least, serious *ambiguities* in the description.

We basically argue, in this and in previous papers, that the power of Euler's function – as a mathematical description of what we believe to be a real particle – has not been fully exploited. We,

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[12] John P. Ralston, *How to understand quantum mechanics* (2017), p. 1-10. For the record, the 'stop wasting electrons' request is Dr. Ralston's.

[13] For course details, see: https://www.edx.org/course/quantum-mechanics-wavefunctions-operators-and-expectation-values. Our scores on module one (out of three) were initially fairly consistent but then the course staff made us understand the course was meant to learn how to do quantum-mechanical calculations – as opposed to questioning basic principles. In general, we benefitted most from the remarks of some fellow students – some of whom wrote us to say our remarks had effectively served as an eye-opener. We only did one module – and we decided not to do the exam because – as mentioned – one should not avoid calculations, but one should avoid *mindless* calculations.

[14] We will offer a summary only here. For a more comprehensive discussion, see: Jean Louis Van Belle, *Euler's function and the double life of –1*, 30 October 2018, http://vixra.org/pdf/1810.0339v2.pdf.

[15] See the acknowledgements above (*Occam's Razor*).

therefore, have a redundancy in the description. The fallacy is illustrated below. When we combine −1 with an amplitude, we should not think of it as a scalar: we should think of −1 as a complex number itself. Hence, when we are multiplying a set of amplitudes – let's say *two* amplitudes, to focus our mind (think of a beam splitter or alternative paths here) – with −1, we are *not* necessarily multiplying them with the same thing: −1 is *not* necessarily a common phase factor. The phase factor may be +π or, alternatively, −π. To put it simply, when going from +1 to −1, it matters how you get there – and vice versa.

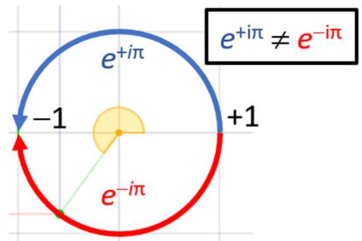

Figure 1: $e^{+i\pi} \neq e^{-i\pi}$

Let us elaborate this. Quantum physicists don't think of the elementary wavefunction as representing anything real but – if they do – they would reluctantly say it might represent some theoretical spin-zero particle. Now, we all know spin-zero particles do not exist. All *real* particles have spin – electrons, photons, anything – and spin (a shorthand for angular momentum) is always in one direction or the other: it is just the *magnitude* of the spin that differs. Hence, it is rather odd that the plus/minus sign of the imaginary unit in the $a \cdot e^{\pm i\theta}$ function is *not* being used to include spin in the mathematical description. Indeed, most introductory courses in quantum mechanics will show that both $a \cdot e^{-i \cdot \theta} = a \cdot e^{-i \cdot (\omega t - kx)}$ and $a \cdot e^{+i \cdot \theta} = a \cdot e^{+i \cdot (\omega t - kx)}$ are acceptable waveforms for a particle that is propagating in a given direction.[16] We would think physicists would then proceed to provide some argument why one would be better than the other, or some discussion on why they might be different, but that is not the case. The professors usually conclude that "the choice is a matter of convention" and, that "happily, most physicists use the same convention."[17]

Historical experience tells us theoretical or mathematical possibilities in quantum mechanics often turn out to represent real things – think, for example, of the experimental verification of the existence of the positron (or of anti-matter in general) after Dirac had predicted its existence based on the mathematical possibility only. So why would that *not* be the case here? Occam's Razor principle tells us that we should not have any redundancy in the description. Hence, if there is a physical interpretation of the wavefunction, then we should not have to choose between the two mathematical possibilities: they would represent two different physical situations, and the one obvious characteristic that would distinguish the two physical situations is the spin direction. Hence, we do *not* agree with the mainstream view that the choice is a matter of convention. Instead, we dare to suggest that the two mathematical possibilities represent identical particles with opposite spin. Combining this with the two possible directions of propagation (which are given by the +– or ++ signs in front of ω and k), we get the following table:

[16] These arguments usually show *other* waveforms – such as, for example, a real-valued sinusoid – are *not* acceptable.
[17] See, for example, the edX Course 8.04.1*x* which is organized by the MIT. Precise reference: edX Course 8.04.1*x* Lecture Notes, Chapter 4, Section 3.

Table 1: Occam's Razor: mathematical possibilities versus physical realities

Spin and direction of travel	**Spin up (e.g. $J = +\hbar/2$)**	**Spin down (e.g. $J = -\hbar/2$)**
Positive *x*-direction	$\psi = a \cdot e^{-i\cdot(\omega t - kx)}$	$\psi^* = a \cdot e^{+i\cdot(\omega t - kx)}$
Negative *x*-direction	$\chi = a \cdot e^{-i\cdot(\omega t + kx)}$	$\chi^* = a \cdot e^{-i\cdot(\omega t + kx)}$

Let us think this through. Feynman's argument[18] that wavefunctions of spin-1/2 particles (which is what we are thinking of here) have a weird 720° symmetry This weird symmetry is not there for spin-1 particles. Hence, intuition tells us that it should disappear when we would use the two mathematical possibilities for describing the wavefunction of a particle to distinguish between two particles that are identical but have opposite spin. If our intuition is correct (we do not have a formal proof of this – but we do have the mentioned *heuristic disproof*[19]), then the most important objection to a physical interpretation of the wavefunction would no longer be valid and, in our humble view, it would trigger a whole new wave (pun intended) of geometric (read: physical) interpretations of the wavefunction.

For starters, it would get rid of the desiccated idea that the complex conjugate of the (elementary) $\psi = \exp(i\theta) = \exp[i(kx-\omega t)]$ function – so that is $\psi^* = \exp(-i\theta) = \exp[i(\omega t-kt)]$ – is just another *mathematical* possibility to describe reality. In other words, it would get rid of the idea that it is just some *convention.*[20] Let us mention some (possible) implications so as to illustrate the point.

The idea of associating the complex conjugate of a wavefunction with a particle that's identical except for its (opposite) spin might be outlandish, which is why we should first try to connect with a much simpler idea – which might or might not be more palatable: the complex conjugate of a wavefunction obviously reverses the trajectory of the particle in space and in time: $\boldsymbol{x}$ becomes $-\boldsymbol{x}$ and t becomes $-t$.

What? Yes. A true physical interpretation will present the real and imaginary part of the elementary wavefunction $a \cdot e^{i\theta}$ as *real* field vectors driven by the same function but with a phase difference of 90 degrees:

$$a \cdot e^{i\theta} = a \cdot (\cos\theta + i \cdot \sin\theta) = a \cdot \sin(\theta + \pi/2) + i \cdot a \cdot \sin\theta$$

However, a minus sign in front of our $\exp(i\theta)$ function reverses the direction of the oscillation – in space and, importantly, *in time too*. Here we can use the $\cos\theta = \cos(-\theta)$ and $\sin\theta = -\sin(-\theta)$ formulas to relate $-\exp(i\theta)$ to the complex conjugate. We write:

$$-\psi = -\exp(i\theta) = -(\cos\theta + i \cdot \sin\theta) = \cos(-\theta) + i \cdot \sin(-\theta) = \exp(-i\theta) = \psi^*$$

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[18] See: Feynman's *Lectures*, Volume III, Chapter 6. The term we use here ('Feynman's argument') is, obviously, used as a shorthand for a more general argument. We admit we did not have the time – or the energy – to fully investigate other versions of the same argument. We understand Feynman's argument is a *thought* experiment only. We do not have the required mathematical skills to investigate more general arguments proving the same. Hence, we do understand our critics, who will say we are only trying to make some waves here. To those critics, we are saying: we are trying hard – *very* hard – to speak your language. Hence, those critics should, perhaps, try to speak more of *our* language. Think Wittgenstein-II and Hegel. 😉

[19] Jean Louis Van Belle, *Euler's function and the double life of –1*, 30 October 2018, http://vixra.org/pdf/1810.0339v2.pdf.

[20] We apologize (and then, arrogant as we are, we do not – of course) for insisting on this point. We readily admit we don't like such *conventions*: Occam tells us the degrees of freedom (and we are talking some plain *number* here) in the mathematical description should match the degrees of freedom in our *measurement* of whatever we think reality might be. The idea of just *settling* on a mathematical convention in this particular context (a mathematical object describing a physical reality) is, for us, plain *anathema*.

So, what happens? What are we doing? Do we have another ambiguity in the description? No. We don't. Here we need to highlight a subtle point. Time has one direction only. We cannot reverse time. We can only reverse the direction in space. We can do so by reversing the momentum of a particle. If we do so, the $\mathbf{k} = \mathbf{p}/\hbar$ in the argument of the wavefunction becomes $-\mathbf{k} = -\mathbf{p}/\hbar$. However, the energy remains what it is and, hence, nothing happens to the $\omega \cdot t = (E/\hbar) \cdot t$ term. Hence, our wavefunction becomes $\exp[i(-\mathbf{k} \cdot \boldsymbol{x} - \omega \cdot t)]$, and we can calculate the wave velocity as negative: $v = -\omega/|\mathbf{k}| = -\omega/k$. The wave effectively travels in the opposite direction (i.e. the *negative* *x*-direction in one-dimensional space). Hence, we can think of opposite directions in space, but we can't reverse time. Why not?

The answer is related to how our mind works. Time has one direction only because – if it wouldn't – we would not be able to describe trajectories in spacetime by a well-behaved function. We really don't need to think of entropy or of other more convoluted explanations here. The diagrams below illustrate the point. The spacetime trajectory in the diagram on the right is not *kosher*, because our object travels back in time in not less than three sections of the graph. Spacetime trajectories need to be described by well-defined function: for every value of *t*, we should have one, and only one, value of *x*. The reverse is not true, of course: a particle can travel back to where it was. Hence, it is easy to see that our concept of time going in one direction, and in one direction only, implies that we should only allow well-behaved functions.

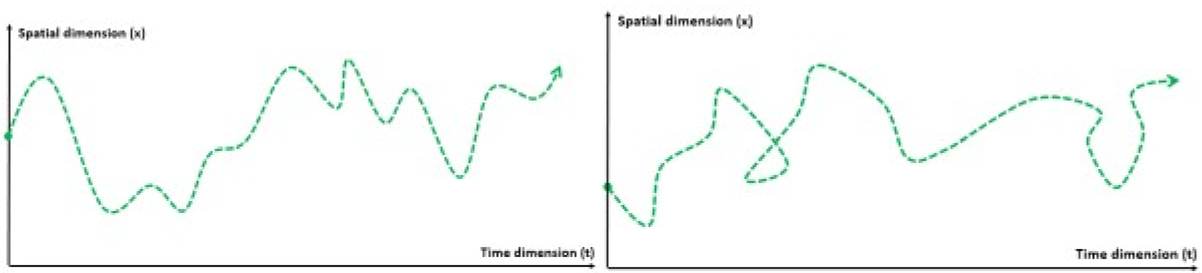

Figure 2: A well- and a not-well behaved trajectory in spacetime

It may be a self-evident point to make but it is an important one. It shows us we should not be worried: our *new* interpretation of the wavefunction – incorporating spin – is fully consistent. It rules out any ambiguity. It we would *not* accept it, then we would have two *mathematical* possibilities to describe a theoretical spin-zero particle that would travel in the *negative* *x*-direction[21]: $\psi = \exp[i(-kx-\omega t)]$ *or*, alternatively, $-\psi = \psi^* = \exp[i(kx+\omega t)]$.

An added benefit of our interpretation is that it eliminates the logic that leads to the rather uncomfortable conclusion that the wavefunction of spin-1/2 particles (read: electrons, practically speaking) has some weird 720-degree symmetry in space. This conclusion is uncomfortable because we cannot imagine such objects in space without invoking the idea of some kind of relation between the subject and the object (the reader should think of the Dirac belt trick here). It has, therefore, virtually halted all creative thinking on a physical interpretation of the wavefunction.[22]

This may sound like Chinese to the reader, so let us proceed to something else: how should we interpret the product of the elementary function with its complex conjugate? In orthodox quantum mechanics, it is just this weird thing: some number that will be *proportional* to some *probability*. In our interpretation, this probability is proportional to energy densities – or, because of the energy-mass equivalence – to

[21] We are not just switching back and forth between one- and three-dimensional wavefunctions here: think of *choosing* the reference frame such that the *x*-axis coincides with the direction of propagation of the wave.

[22] See: Jean Louis Van Belle, *Euler's Wavefunction: the Double Life of –1*, http://vixra.org/abs/1810.0339.

mass densities. Let us take the simplest of cases and think of the ⟨ψ| *state* as some very *generic* thing being represented by a *generic* complex function[23]:

$$\langle\psi| \cong a \cdot e^{i\theta}$$

The ⟨ψ|⟨ψ|* = ⟨ψ||ψ⟩ product then just eliminates the *oscillation*. It freezes time, we might say:

$$\langle\psi|\langle\psi|^* = \langle\psi||\psi\rangle = a \cdot e^{i\theta} \cdot a \cdot e^{-i\theta} = a^2 \cdot e^0 = a^2$$

Hence, we end up with one factor of the energy of an oscillation: its amplitude (a). Let us think about this for a brief moment. To focus our minds, let us think of a photon. The energy of any oscillation will always be proportional to (1) its amplitude (a) and (2) its frequency (f). Hence, if we write the proportionality coefficient as k, then the energy of our photon will be equal to:

$$\mathrm{E} = k \cdot a^2 \cdot \omega^2$$

What should we use for the amplitude of the oscillation here? It turns out we get a nice result using the *wavelength*[24]:

$$\mathrm{E} = ka^2\omega^2 = k\lambda^2\frac{\mathrm{E}^2}{h^2} = k\frac{h^2c^2}{\mathrm{E}^2}\frac{\mathrm{E}^2}{h^2} = kc^2 \Leftrightarrow k = \mathrm{m} \text{ and } \mathrm{E} = \mathrm{m}c^2$$

However, we should immediately note that – in our interpretation(s) of the wavefunction – this assumes a circularly polarized wave. Its linear components – the sine and cosine, that is – will only pack *half* of that energy. Our electron model – *zbw* electron as well an orbital electron – is based on the same. Now that we are here, we will quickly write down the formulas we found:

Table 2: Intrinsic spin versus orbital angular momentum

Spin-only electron (*Zitterbewegung*)	**Orbital electron (Bohr orbitals)**
$\mathrm{S} = \mathrm{h}$	$\mathrm{S}_n = n\mathrm{h}$ for $n = 1, 2, \ldots$
$\mathrm{E} = \mathrm{m}c^2$	$\mathrm{E}_n = -\frac{1}{2}\frac{\alpha^2}{n^2}\mathrm{m}c^2 = -\frac{1}{n^2}\mathrm{E}_R$
$r = r_\mathrm{C} = \frac{\hbar}{\mathrm{m}c}$	$r_n = n^2 r_\mathrm{B} = \frac{n^2 r_\mathrm{C}}{\alpha} = \frac{n^2}{\alpha}\frac{\hbar}{\mathrm{m}c}$
$v = c$	$v_n = \frac{1}{n}\alpha c$
$\omega = \frac{v}{r} = c \cdot \frac{\mathrm{m}c}{\hbar} = \frac{\mathrm{E}}{\hbar}$	$\omega_n = \frac{v_n}{r_n} = \frac{\alpha^2}{n^3\hbar}\mathrm{m}c^2 = \frac{\frac{1}{n^2}\alpha^2\mathrm{m}c^2}{n\hbar}$

[23] Our critics will cry wolf and say we should be more general. They are right. However, let us make two remarks here. First, we should note that QED is a linear theory and, hence, we can effectively - and very easily – generalize anything we write to a Fourier superposition of waves. We use the ≅ symbol to indicate an *equivalence*. It's not an identity. To mathematical purists – who will continue to cry wolf no matter what we write because they won't accept the $e^{-\pi} \neq e^{-\pi}$ expression either – we will admit it is more like a symbol showing *congruence*. Second, we do get some physical laws out of physics (both classical as well as quantum-mechanical) that are likely to justify the general $a \cdot e^{i\theta}$ shape.

[24] We use the Eλ = hc ⇔ λ = hc/E identity. The reader might think we should use the amplitude of the electric and magnetic field. We could – the model is consistent – but it requires some extra calculations as we then need to think of the energy as some force over a distance. We refer to our papers for more details.

$\mathrm{L} = I \cdot \omega = \frac{\hbar}{2}$	$\mathrm{L}_n = I \cdot \omega_n = n\hbar$
$\mu = \mathrm{I} \cdot \pi {r_\mathrm{C}}^2 = \frac{\mathrm{q_e}}{2\mathrm{m}}\hbar$	$\mu_n = \mathrm{I} \cdot \pi {r_n}^2 = \frac{\mathrm{q_e}}{2\mathrm{m}} n\hbar$
$\mathrm{g} = \frac{2\mathrm{m}}{\mathrm{q_e}}\frac{\mu}{\mathrm{L}} = 2$	$\mathrm{g}_n = \frac{2\mathrm{m}}{\mathrm{q_e}}\frac{\mu}{\mathrm{L}} = 1$

We will come back to this in the next section of our paper. Let us first relate the discussion to the discussion to the *Hermiticity* of (many) operators. If A is an operator[25], then it could operate on some state |ψ⟩. We write this operation as:

$$A|\psi\rangle$$

Now, we can then think of some (probability) amplitude that this operation produces some other state |φ⟩, which we would write as:

$$\langle\varphi|A|\psi\rangle$$

We can now take the complex conjugate:

$$\langle\varphi|A|\psi\rangle^* = \langle\psi|A^\dagger|\varphi\rangle$$

A† is, of course, the conjugate transpose of A: $A^\dagger_{ij}=(A_{ji})^*$, and we will call the operator (and the matrix) Hermitian if the conjugate transpose of this operator (or the matrix) gives us the same operator matrix, so that is if A† = A. Many operators are Hermitian. Why? Well… What is the meaning of ⟨φ|A|ψ⟩* = ⟨ψ|A†|φ⟩ = ⟨ψ|A|φ⟩? Well… In the ⟨φ|A|ψ⟩ we go from some state |ψ⟩ to some other state ⟨φ|. Conversely, the ⟨ψ|A|φ⟩ expression tells us we were in state |φ⟩ but now we are in the state ⟨ψ|.

So, is there some meaning to the complex conjugate of an amplitude like ⟨φ|A|ψ⟩? We say: yes, there is! Read up on time reversal and CPT symmetry! Based on the above – and your reading-up on CPT symmetry – we would think it is fair to say we should interpret the Hermiticity condition as a *physical* reversibility condition.

We are not talking mere time symmetry here: reversing a physical process is like playing a movie backwards and, hence, we are actually talking CPT symmetry here. Of course, it may be difficult to *prove* this interpretation – can one prove interpretations, really? – but, at the very least, we made a start, right? 😆

Explaining QED using classical theory

The following series of diagrams summarizes some of what we covered in our previous papers on a physical interpretation of the wavefunction.

[25] We should use the *hat* because the symbol without the hat is reserved for the *matrix* that does the operation and, therefore, A already assumes a representation, i.e. some chosen set of base states. However, let us skip the niceties here.

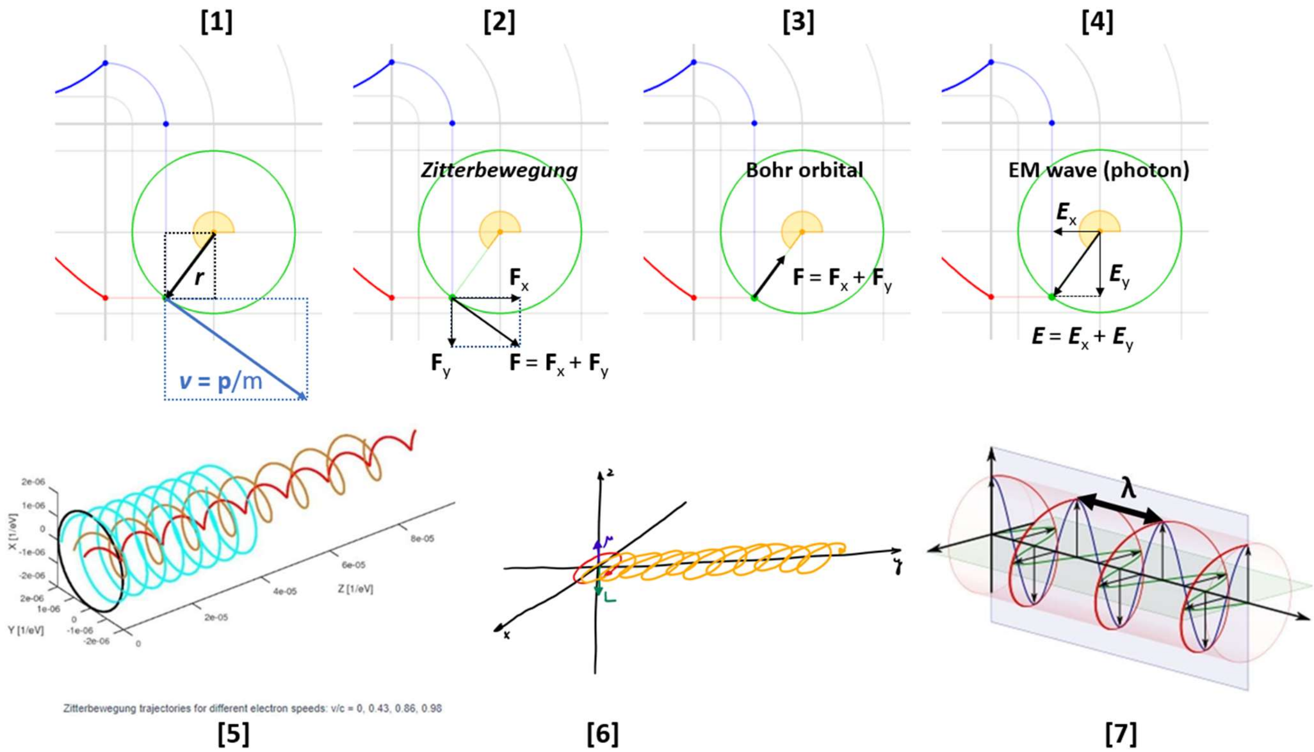

Figure 3: Physical interpretations of the wavefunction

We refer to our previous papers for a detailed discussion of each of these.[26] Here we will just sum up the basics.

1. We had a *Zitterbewegung* model, in which the elementary wavefunction represents a pointlike *charge* with zero rest mass and which, therefore, moves at the speed of light. This model explains Einstein's energy-mass equivalence relation in terms of a two-dimensional oscillation. The radius of the oscillation is the Compton radius of the electron.

2. The *Zitterbewegung* electron – which combines the idea of a pointlike charge and Wheeler's idea of mass without mass[27] – can then be inserted into Bohr's quantum-mechanical model of an atom, which can also be represented using the elementary wavefunction. We have a different force configuration here (because of the positively charged nucleus, we have a centripetal force now – as opposed to the tangential *zbw* force) but Euler's $a \cdot e^{\pm i\theta}$ function still represents an actual *position vector* of an electron which – because it acquired a rest mass from its *Zitterbewegung* – now moves at velocity $v = (\alpha/n) \cdot c$.[28] This should suffice to explain diagram 1, 2 and 3 below.

3. Diagram 4 represents the idea of a photon that we get out of the Bohr model. We referred to it as the one-cycle photon model. The idea is the following. The Bohr orbitals are separated by a amount of

[26] See our series of viXra papers (http://vixra.org/author/jean_louis_van_belle). If we would have to choose one which sort of sums most, we would select our *Layered Motions: The Meaning of the Fine-Structure Constant* (http://vixra.org/pdf/1812.0273v3.pdf).

[27] The mass of the electron is the equivalent mass of the energy in the oscillation.

[28] The n is the number of the Bohr orbital (n = 1, 2, 3…). The α and c are the fine-structure constant and the speed of light. This formula comes out naturally of the Bohr model. See the referenced papers.

(physical) action that is equal to *h*. Hence, when an electron jumps from one level to the next – say from the second to the first – then the atom will lose one unit of *h*. Our photon will have to pack that, somehow. It will also have to pack the related energy, which is given by the *difference* of the energies of the two orbitals. This gives us not only the Rydberg formula – Bohr sort of *explained* that formula in 1913 already, but not like we do here – but also a delightfully simple model of a photon and an intuitive interpretation of the Planck-Einstein relation (f = 1/T = E/h) for a photon. Indeed, we can do what we did for the electron, which is to express *h* in two alternative ways: (1) the product of some momentum over a distance and (2) the product of energy over some time. We find, of course, that the distance and time correspond to the wavelength and the cycle time:

$$h = \mathrm{p} \cdot \lambda = \frac{\mathrm{E}}{c} \cdot \lambda \Leftrightarrow \lambda = \frac{hc}{\mathrm{E}}$$

$$h = \mathrm{E} \cdot \mathrm{T} \Leftrightarrow \mathrm{T} = \frac{h}{\mathrm{E}} = \frac{1}{f}$$

Needless to say, the E = mc^2 mass-energy equivalence relation can be written as p = mc = E/c for the photon. The two equations are, therefore, wonderfully consistent:

$$h = \mathrm{p} \cdot \lambda = \frac{\mathrm{E}}{c} \cdot \lambda = \frac{\mathrm{E}}{f} = \mathrm{E} \cdot \mathrm{T}$$

We calculated the related force and field strength in our paper[29] so we won't repeat ourselves here. We would just like to point out something interesting – using diagram 5 above. Diagram 5 was copied from one of the many papers of Celani, Vassallo and Di Tommaso on the *Zitterbewegung* model, but we can use it to illustrate how and why we can associate a *radius* with the wavelength of a photon. Indeed, the diagram shows that, as an electron starts moving along some trajectory at a relativistic velocity – a velocity that becomes a more substantial fraction of *c*, that is – then the radius of the *Zitterbewegung* oscillation becomes smaller and smaller. In the limit ($v \rightarrow c$), it becomes zero ($r \rightarrow 0$), and the *circumference* of the oscillation becomes a simple (linear) wavelength in the process (this is illustrated in diagram 5 and 7, which provides a geometric interpretation of the *de Broglie* wavelength). Now, if we write this wavelength as λ_C (this is, of course, the Compton *wavelength*), then we get the usual relationship between a radius and a wavelength: $r_C = \lambda_C/2\pi$. This, then, provides an intuitive interpretation of the Eλ = *hc* equation for the photon and – more importantly – an intuitive explanation of the 2π factor in the formula for the fine-structure constant as a coupling constant. We write:

$$\alpha = \frac{2\pi \cdot \mathrm{q_e}^2}{h \cdot c} = \frac{k \cdot \mathrm{q_e}^2}{\hbar \cdot c} = \frac{\mathrm{F_B} \cdot r_\mathrm{B}^2}{\mathrm{F_\gamma} \cdot r_\gamma \cdot r_\gamma} = \frac{\mathrm{F_B} \cdot r_\mathrm{B}^2}{\mathrm{F_\gamma} \cdot r_\gamma^2} = \frac{\mathrm{E_B} \cdot r_\mathrm{B}}{\mathrm{E_\gamma} \cdot r_\gamma}$$

Needless to say, E_B, F_B, r_B and E_γ, F_γ, r_γ are the energies, forces and radii that are associated with the Bohr orbitals and our one-cycle photon.[30]

Finally – but this is a much finer and more philosophical point – diagram 5 gives us an intuitive geometric interpretation of one of the many ways in which Planck's quantum of action may express itself: the quantization of space. Indeed, at v = 0 (diagram 2), we have perfectly circular motion of a pointlike charge moving at the velocity of light, and we may associate Planck's quantum of action with the surface area of the circle. However, at v = c, the motion is purely linear – but we still think of the rotating field

[29] See the above-mentioned paper: Jean Louis Van Belle, *Layered Motions: The Meaning of the Fine-Structure Constant*, 23 December 2018, http://vixra.org/pdf/1812.0273v3.pdf.

[30] These formulas may appear as mind-boggling to the reader. If so, we advise the reader to first look at our other papers, whose pace is much more gradual.

vector at the core (diagram 4). Planck's quantum of action now expresses itself space as a linear distance: the wavelength of the photon. We like to express this dual view as follows:

$$zbw\ electron: \mathrm{S} = h = \mathrm{p}_{Compton} \cdot \lambda_{Compton} = \mathrm{m_e} c \lambda_{\mathrm{C}} = \mathrm{m_e} c \cdot 2\pi r_{\mathrm{C}} = \mathrm{m_e} c \frac{h}{\mathrm{m_e} c} = h$$

$$photon: \mathrm{S} = h = \mathrm{p}_{phot} \quad \cdot \lambda_{photo} \quad = \frac{\mathrm{E}_\gamma}{c} \lambda_\gamma = \mathrm{m}_\gamma c \lambda_\gamma = \mathrm{m}_\gamma c \cdot 2\pi r_\gamma = \mathrm{m}_\gamma c \frac{hc}{\mathrm{E}_\gamma} = h$$

To be fully complete, we can add the same equation for the Bohr orbitals:

$$n^{th}\ Bohr\ orbital: \mathrm{S} = n \cdot h = \mathrm{p}_n \cdot \lambda_n = \mathrm{m}_e v_n \lambda_n = \mathrm{m}_e \frac{\alpha c}{n} 2\pi \frac{n^2 \hbar}{\alpha \mathrm{m}_e c} = n \cdot h$$

We like these expressions because – in our humble view – there is no better way to express the idea that we should associate Planck's quantum of action (or any multiple of it) with the idea of a *cycle* in Nature.[31]

We can imagine the reader is, by now, quite tired of these gymnastics. He or she should ask: what does it all mean? We would like to refer to some history here. Prof. Dr. Alexander Burinskii – the author of the Dirac-Kerr-Newman electron model – told us he had started to further elaborate the *Zitterbewegung* model in the year the author of this paper was born – that is in 1969. He published an article on this in the *Journal of Experimental and Theoretical Physics* (JETP)[32]. However, he told us he had always been puzzled about this one question: what keeps the pointlike charge in the *zbw* electron in its circular orbit? He, therefore, moved to exploring Kerr-Newman geometries – which has resulted in his Dirac-Kerr-Newman model of an electron.[33]

While the Dirac-Kerr-Newman model is a much more advanced model – it accommodates the theory of the supersymmetric Higgs field and string theory – we understand it does reduce to its classical limit, which is the *Zitterbewegung* model, if one limits the assumptions to general relativity and classical electromagnetism only. In our modest view, this validates our model. There is no mystery on the *zbw* force, we think: it is just the classical Lorentz force **F** = q**E** + q***v***×**B**. We, therefore, think that the *zbw* force results from the very same electric and magnetic field oscillation that makes up the photon. It is just the way that Planck's quantum of action expresses itself in space that is different here: we just get a different *form factor*, so to speak, when we look at the pointlike *zbw* charge. This, then, should solve Mr. Burinskii's puzzle – in our humble view, that is.

Finally, the attentive reader will have noticed that we did *not* discuss diagram 6. We inserted this diagram because when we considered the various *degrees of freedom* in interpreting Euler's wavefunction, we thought we should, perhaps, not necessarily assume that the plane of the circulatory motion – the *zbw* motion of the pointlike charge in the diagram – is perpendicular to the direction of propagation. In fact, the Stern-Gerlach experiment tells us the magnetic moment is literally *up* or *down*, which assumes the plane of the electric current should be parallel to the direction of motion. We like this alternative picture of the *zbw* electron because – intuitively – we feel it might provide us with some

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[31] Our model also offers a much more comprehensive understanding of the fine-structure constant as a scaling constant. See: Jean Louis Van Belle, *Layered Motions : The Meaning of the Fine-Structure Constant*, http://vixra.org/abs/1812.0273.

[32] Burinskii, A.Y., *Microgeons with spin*, Sov. Phys. JETP 39 (1974) 193. One should note that Prof. dr. Burinskii refers to the *zbw* charge as an 'electron photon' or the 'electron EM wave'. However, its function in the model is basically the same. Prof. dr. Burinskii also told us that he was told *not* to refer to the *Zitterbewegung* model at the time, because it was seen as a classical model and, therefore, not in tune with the modern ideas of quantum mechanics.

[33] See the references above.

kind of *physical* explanation of relativistic length contraction: as velocities increase, the radius of the circular motion becomes smaller which, in this model, may be interpreted as a contraction of the size of the *zbw* electron.[34]

Can we explain quantum-mechanical interference, i.e. the interference of a photon with itself in, say, a Mach-Zehnder interferometer? We think we can. We think of a photon as the sum of two linearly polarized waves. We write:

$$\cos\theta + i\cdot\sin\theta = e^{i\cdot\theta} \text{ (RHC)}$$

$$\cos(-\theta) + i\cdot\sin(-\theta) = \cos\theta - i\cdot\sin\theta = e^{-i\cdot\theta} \text{ (LHC)}$$

We, therefore, have an alternative theory of what happens in the Mach-Zehnder interferometer:

1. The incoming photon is circularly polarized (left- or right-handed).
2. The first beam splitter splits our photon into two linearly polarized waves.
3. The mirrors reflect those waves and the second beam splitter recombines the two linear waves back into a circularly polarized wave.
4. The positive or negative interference then explains the binary outcome of the Mach-Zehnder experiment – at the level of a photon – *in classical terms*.

We detailed this in a previous paper[35] and, hence, we will not repeat ourselves here. We will only note that we do *not* think this is a comprehensive explanation of the phenomenon. However, it does serve to show that a classical explanation – i.e. an explanation in terms of wave shapes and other form factors – should be possible.

In this regard, we would link this to more recent theory and experiments that focus on how slits or holes affect wave *shapes* as electrons – or photons – go through them. The diagram below illustrates the point that we are trying to make here.[36] We do think these are *very* promising in terms of offering some kind of classical (physical) explanation for interference and/or diffraction.

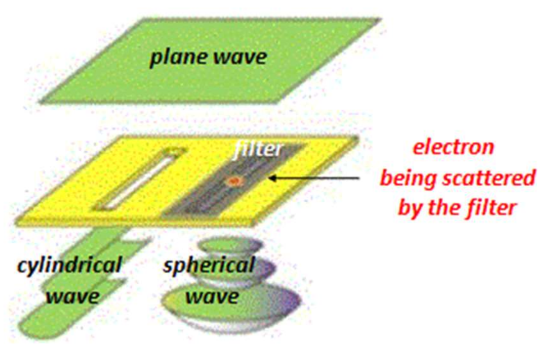

Figure 4: Physical interpretations of the electron wave

[34] This is just a random thought at the moment. It needs further exploration.

[35] Jean Louis Van Belle, *A Classical Explanation for the One-Photon Mach-Zehnder Experiment*, 29 December 2018, http://vixra.org/abs/1812.0455.

[36] The definition is somewhat random but we think of diffraction if there is only one slit or hole. In contrast, the idea of interference assumes two or more wave sources. The research we refer to is the work of the Italian researchers Stefano Frabboni, Reggio Emilia, Gian Carlo Gazzadi, and Giulio Pozzi, as reported on the phys.org site (https://phys.org/news/2011-01-which-way-detector-mystery-doubleslit.html). The illustration was taken from the same source, but the author of this paper added the explanatory tags.

All that is left to explain – for the photon as well as the electron – is why the whole oscillation seems to stick together upon detection. We admit that's not easy to do. But – as an idea – it is definitely easier to accept this *axiom* than whatever other theory is on the market right now.

Conclusions

The text speaks for itself. There is no need for a summary. If one would insist, we would sum it all up as follows: it is about time physicists consider the *form factor* in their analysis. It somehow disappeared. Vector equations become *flat*: vector quantities became magnitudes. Schrödinger's equation should be rewritten as a vector equation.

What about uncertainty? Nothing – absolutely *nothing* – of what we wrote above involves any uncertainty. It must be there somewhere, right? We would like to offer the following reflection. We have a few footnotes in previous papers, in which we suggest that Planck's quantum of action should be interpreted as a *vector*. The uncertainty – or the probabilistic nature of Nature, so to speak[37] – might, therefore, not be in its *magnitude*. We feel the uncertainty is in its *direction*. This may seem to be restrictive. However, because *h* is the product of a force (some *vector* in three-dimensional space), a distance (another three-dimensional concept) and time, we think the mathematical framework comes with sufficient degrees of freedom to describe any situation.

Jean Louis Van Belle, 31 December 2018

References

All references are in the text and/or footnotes.

[37] A fair amount of so-called thought experiments in quantum mechanics – and we are not (only) talking the more popular accounts on what quantum mechanics is supposed to be all about – do *not* model the uncertainty *in Nature*, but on *our* uncertainty on what might actually be going on. Einstein was not worried about the conclusion that Nature was probabilistic (he fully agreed we cannot know everything): a quick analysis of the full transcriptions of his oft-quoted remarks reveal that he just wanted to see a theory that *explains* the probabilities. A theory that just *describes* them didn't satisfy him.