Mass without mass

Jean Louis Van Belle, 13 August 2019

Synopsis

In this paper, we revisit the oscillator model of an electron, applying Wheeler's 'mass without mass' concept to the *Zitterbewegung* model of an electron. We then use this model to derive the electron properties (spin, magnetic moment, energy, etcetera). We also use this model to calculate the *Zitterbewegung* force and the implied energy densities inside of the electron. Finally, we offer some reflections on how this simple but complete 'mass without mass' model may provide a basis for a *realist* interpretation of quantum mechanics.

Contents

Mass without mass

Introduction

Force and energy are fundamental concepts in physics. What about mass? Isn't that equally fundamental? Not really. The new 2019 system of SI units did away with the *kilogram* as a fundamental unit of mass: mass is now also *derived* from a limited set of natural constants, most notably Planck's quantum of action. In addition, Einstein's E/m = c^2 tells us that, while mass and energy are not one and the same thing, the two concepts are, somehow, *equivalent*. The question is: how *exactly*?

Look at how we re-write Einstein's mass-energy equivalence relation: E/m = c^2. Isn't that remarkable? The ratio of the energy and the mass of *any* particle we can think of – stable or unstable, elementary or not – is equal to the squared speed of light, *always*. In fact, the formula is valid for any object, and for any *system* of objects – regardless of the moving parts inside. That's why John Wheeler coined the term '*mass without mass*' in the early 1960s.

How can one explain mass without mass? We will look at this in the context of the *Zitterbewegung* model of an electron.

A brief history of the idea

You may or may not have heard about this model. Let us recap the basics. Erwin Schrödinger stumbled upon this idea when he was exploring solutions to Dirac's wave equation for free electrons. It's worth quoting Dirac's summary of it:

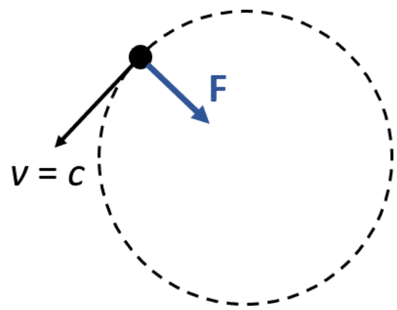
> "The variables give rise to some rather unexpected phenomena concerning the motion of the electron. These have been fully worked out by Schrödinger. It is found that an electron which seems to us to be moving slowly, must actually have a very high frequency oscillatory motion of small amplitude superposed on the regular motion which appears to us. As a result of this oscillatory motion, the velocity of the electron at any time equals the velocity of light. This is a prediction which cannot be directly verified by experiment, since the frequency of the oscillatory motion is so high and its amplitude is so small. But one must believe in this consequence of the theory, since other consequences of the theory which are inseparably bound up with this one, such as the law of scattering of light by an electron, are confirmed by experiment." (Paul A.M. Dirac, *Theory of Electrons and Positrons*, Nobel Lecture, December 12, 1933)

Let us say a few words about the "law of scattering of light by an electron." You've probably heard a photon can be scattered elastically or inelastically: Compton versus Thomson scattering. Compton scattering involves electron-photon interference: a high-energy photon (the light is X- or gamma-rays) will hit an electron and its energy is briefly absorbed before the electron comes back to its equilibrium situation by emitting another photon. The wavelength of the emitted photon will be longer. The photon has, therefore, less energy, and the difference in the energy of the incoming and the outgoing photon gives the electron some linear momentum. Because of the interference effect, Compton scattering is referred to as inelastic. In contrast, low-energy photons scatter elastically. Elastic scattering experiments yield a much smaller effective radius of the electron. It is the so-called classical electron radius, which is also known as the Thomson or Lorentz radius, and it is equal to a fraction (α) of the Compton radius. To be precise, $r_e = \alpha \cdot r_C \approx 0.0073 \cdot r_C \approx 2.818 \times 10^{-15}$ m. The Thomson scattering radius is referred to as *elastic* because the photon seems to bounce off some hard *core*: there is no interference.

The *Zitterbewegung* model

OK. So what's the *Zitterbewegung* model of an electron? We think of the hard core as the pointlike charge. Note that pointlike doesn't mean it has no dimension whatsoever: 10^{-15} m is small – the *femto*meter scale – but it's not zero. Pointlike means we consider it has no internal structure. In contrast, we think the electron has a structure. What structure? It's that high frequency oscillatory motion of small amplitude. That's why the electron itself has a different radius: the Compton radius. The idea is illustrated below (Figure 1).

Figure 1: The electron as a current ring



We have a pointlike charge in a circular orbit here. Its tangential velocity equals the product of the radius and the angular velocity: $v = a \cdot \omega$ formula. The tangential velocity is the speed of light: $v = c$. Hence, the *rest* mass of this pointlike charge must be zero. However, there is *energy* in this oscillation, and we think of the rest mass of the electron as the equivalent mass of the energy in the oscillation. This hybrid description of the electron is Wheeler's idea of mass without mass: the mass of the electron is the equivalent mass of the energy in the oscillation of the pointlike charge.

We can now calculate the Compton radius. The calculation is mysteriously simple. The tangential velocity tells us the radius is equal to $a = c/\omega$. The Planck-Einstein relation ($E = \hbar \cdot \omega$) then allows us to substitute ω ($\omega = E/\hbar$). Finally, we can then use Einstein's mass-energy equivalence relation ($E = m \cdot c^2$) to calculate the radius as the ratio of Planck's (reduced) quantum of action and the product of the electron mass and the speed of light:

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

This can be easily interpreted: each *cycle* of the *Zitterbewegung* packs (i) one *fundamental* unit of physical action (h) and (ii) the electron's energy ($E = mc^2$). Indeed, the Planck-Einstein relation can be re-written as $E/T = h$. The $T = 1/f$ in this equation is the cycle time, which we can calculate as being equal to:

$$\mathrm{T} = \frac{h}{\mathrm{E}} \approx \frac{6.626 \times 10^{-34}\ \mathrm{J \cdot s}}{8.187 \times 10^{-14}\ \mathrm{J}} \approx 0.8 \times 10^{-20}\ \mathrm{s}$$

That's a *very* small amount of time: as Dirac notes, we can*not* directly verify this by experiment.[1] The point is: you will now intuitively understand why we can write Planck's quantum of action as the product of the electron's energy and the cycle time:

$$h = E \cdot T = h \cdot f \cdot T = h \cdot f/f = h$$

Hence, we should, effectively, think of one cycle packing not only the electron's energy but also as packing one unit of *h*.

More calculations: the properties of an electron

Now that we're doing some calculations, let's do some more. We can calculate the current:

$$\mathrm{I} = \mathrm{q_e} f = \mathrm{q_e}\frac{\mathrm{E}}{h} \approx (1.6 \times 10^{-19}\ \mathrm{C})\frac{8.187 \times 10^{-14}\ \mathrm{J}}{6.626 \times 10^{-34}\ \mathrm{Js}} \approx 1.98\ \mathrm{A}\ (ampere)$$

This is huge: a household-level current at the sub-atomic scale. However, this result is consistent with the calculation of the magnetic moment, which is equal to the current times the area of the loop and which is, therefore, equal to:

$$\mu = \mathrm{I} \cdot \pi a^2 = \mathrm{q_e}\frac{\mathrm{m}c^2}{h} \cdot \pi a^2 = \mathrm{q_e} c \frac{\pi a^2}{2\pi a} = \frac{\mathrm{q_e} c}{2}\frac{\hbar}{\mathrm{m}c} = \frac{\mathrm{q_e}}{2\mathrm{m}}\hbar$$

It is also consistent with the presumed angular momentum of an electron, which is that of a spin-1/2 particle. Here we must make some assumption as to how the effective mass of the electron will be spread over the disk. If we assume it is spread uniformly over the whole disk[2], then we can use the 1/2 form factor for the moment of inertia (*I*). We write:

$$\mathrm{L} = I \cdot \omega = \frac{ma^2}{2}\frac{c}{a} = \frac{mc}{2}\frac{\hbar}{mc} = \frac{\hbar}{2}$$

We now get the correct g-factor for the pure spin moment of an electron:

$$\boldsymbol{\mu} = -\mathrm{g}\left(\frac{\mathrm{q_e}}{2\mathrm{m}}\right)\mathbf{L} \Leftrightarrow \frac{\mathrm{q_e}}{2\mathrm{m}}\hbar = \mathrm{g}\frac{\mathrm{q_e}}{2\mathrm{m}}\frac{\hbar}{2} \Leftrightarrow \mathrm{g} = 2$$

Let us think this through. What keeps this pointlike charge in its orbit? What makes it 'oscillate' this way? How can we calculate the Compton radius?

The nature of the *Zitterbewegung* force

To keep an object with some momentum in a circular orbit, a centripetal force is needed – as shown in Figure 1. What is the nature of this force? Because the force can only grab onto the charge, it must be electromagnetic. The circular current creates a magnetic flux through the ring which keeps the current going – just like in a superconducting ring. This interpretation has one problem: there is no real material

[1] The cycle time of short-wave ultraviolet light (UV-C), with photon energies equal to 10.2 eV is 0.4×10^{-15} s, so that gives an idea of what we're talking about. You may want to compare with frequencies of X- or gamma-ray photons.
[2] This is a very essential point. It is also very deep and philosophical. We say the energy is in the motion, but it's also in the oscillation. We will come back to this in a moment.

ring to hold and guide our charge in free space, so what keeps this thing *tuned*? We will let this question rest. Let us do some more calculations. What calculations?

We can calculate the centripetal acceleration: it's equal to $a_c = v_t^2/a = a \cdot \omega^2$. This formula is relativistically correct. It might be useful to remind ourselves where this formula comes from. The radius vector $\boldsymbol{a}$ has a horizontal and a vertical component: $x = a \cdot \cos(\omega t)$ and $y = a \cdot \sin(\omega t)$. We can now calculate the two components of the (tangential) velocity vector $\boldsymbol{v} = d\boldsymbol{r}/dt$ as $v_x = -a \cdot \omega \cdot \sin(\omega t)$ and v_x $y = -a \cdot \omega \cdot \cos(\omega t)$. We can now calculate the components of the (centripetal) acceleration vector $\boldsymbol{a_c}$: $a_x = -a \cdot \omega^2 \cdot \cos(\omega t)$ and $a_y = -a \cdot \omega^2 \cdot \sin(\omega t)$. The *magnitude* of the centripetal acceleration vector can then be calculated as:

$$a_c^2 = a_x^2 + a_y^2 = a^2 \cdot \omega^4 \cdot \cos^2(\omega t) + a^2 \cdot \omega^4 \cdot \sin^2(\omega t) = a^2 \cdot \omega^4 \Leftrightarrow a_c = a \cdot \omega^2 = v_t^2/a$$

Now, the force law tells us that F is equal to $F = m \cdot a_c = m \cdot a \cdot \omega^2$. However, what is the mass of our pointlike charge? It has mass because it moves at the velocity of light, but its rest mass is zero. In other words, the relativistic $m = \gamma m_0$ formula yields zero, *always*. Or not? We forget something: the velocity v is equal to c. The Lorentz factor is, therefore, equal to infinity, *always*. So we are multiplying zero with infinity, which gives us… What?

The effective mass of the electron charge

We will refer to γm_0 as the *effective* mass of our pointlike charge. Let us denote it by:

$$m_\gamma = \gamma m_0$$

The subscript – gamma (γ) – is quite apt: it refers to the Lorentz factor, of course. However, theorists such as Burinskii sometimes refer to the pointlike charge as a *toroidal photon* – for an obvious reason, as you can see! Nice, but we need to get on with our calculations. What's the value of m_γ? It shouldn't be zero, and it shouldn't be infinity. It is also quite sensible to think m_γ should be smaller than the rest mass of the electron m_e: it cannot be larger because than the energy of the oscillation would be larger than $E = mc^2$. What could it be? Rather than guessing, we may want to remind ourselves that we know the angular momentum: $L = \hbar/2$. We calculated it using the $L = I \cdot \omega$ formula and using an educated guess for the moment of inertia ($I = m \cdot a^2/2$), but we also have the $\mathbf{L} = \boldsymbol{r} \times \mathbf{p}$ formula, of course! If $\boldsymbol{r} = \boldsymbol{a}$, then we can write the magnitudes as $L = a \cdot p$. We can now calculate m_γ as follows:

1. $L = \hbar/2 \Rightarrow p = L/a = (\hbar/2)/a = (\hbar/2) \cdot m_e \cdot c/\hbar = mc/2$
2. $p = m_\gamma c$

$$\Rightarrow m_\gamma c = m_e c/2 \Leftrightarrow m_\gamma = m_e/2$$

This is a great result: the *effective* mass of the pointlike charge – as it whizzes around the center of the two-dimensional oscillation that makes up our electron – is *half* the (rest) mass of the electron. Hence, we can now write the $F = m \cdot a_c = m \cdot a \cdot \omega^2$ as:

$$F = m_\gamma \cdot a_c = m_\gamma \cdot a \cdot \omega^2 = m_e \cdot a \cdot \omega^2/2$$

The electron as a two-dimensional oscillator

We know energy is force over a distance. The force is a constant here, so we don't need to integrate: a simple product will do. Yes? Perhaps not. To use a simple product, the displacement needs to be measured along the line of force, and our pointlike charge doesn't move along the line of force. Not at all, actually: the motion is perpendicular to it. What should we do? We can analyze the force in terms of its *x*- and *y*-component, and we can think of the circular motion as a superposition of its motion in the *x*- and *y*-direction respectively. This allows us to write the position ***r*** of the pointlike charge in terms of the elementary wavefunction:

$$\boldsymbol{r} = a \cdot e^{i\theta} = x + i \cdot y = a \cdot \cos(\theta) + i \cdot a \cdot \sin(\theta) = a \cdot \cos(\omega t) + i \cdot a \cdot \sin(\omega t) = (x, y)$$

The two force components can be written as the following functions of the *magnitude* of the centripetal (F) and the *x* and *y* coordinates:

- $F_x = F \cdot \cos(\theta - \pi) = -F \cdot \cos(\theta) = -F \cdot x/a$
- $F_y = F \cdot \sin(\theta - \pi) = -F \cdot \sin(\theta) = -F \cdot y/a$

We thus get the following formula for the force[3]:

$$\mathbf{F} = \mathbf{F_x} + \mathbf{F_y} = -F \cdot \cos(\theta) - i \cdot F \cdot \sin(\theta)$$

Calculating the total electron energy

We can now calculate the energy integrals, taking into account the force *reverses* direction when *x* (or *y*) is equal to zero, and that the pointlike charge itself reverses direction when *x* (or *y*) is equal to $\pm a$[4]:

$$\mathrm{E}_x = \int_0^a \mathrm{F}_x \mathrm{d}x - \int_a^0 \mathrm{F}_x \mathrm{d}x + \int_0^{-a} \mathrm{F}_x \mathrm{d}x - \int_{-a}^0 \mathrm{F}_x \mathrm{d}x$$

$$= \int_0^a \frac{\mathrm{F}}{a} x \mathrm{d}x - \int_a^0 \frac{\mathrm{F}}{a} x \mathrm{d}x + \int_0^{-a} \frac{\mathrm{F}}{a} x \mathrm{d}x - \int_{-a}^0 \frac{\mathrm{F}}{a} x \mathrm{d}x$$

$$= \frac{\mathrm{F}}{a}\left[\frac{1}{2}x^2\right]_0^a - \frac{\mathrm{F}}{a}\left[\frac{1}{2}x^2\right]_a^0 + \frac{\mathrm{F}}{a}\left[\frac{1}{2}x^2\right]_0^{-a} - \frac{\mathrm{F}}{a}\left[\frac{1}{2}x^2\right]_{-a}^0$$

$$= \frac{\mathrm{F}}{2}a + \frac{\mathrm{F}}{2}a + \frac{\mathrm{F}}{2}a + \frac{\mathrm{F}}{2}a = 2 \cdot \mathrm{F} \cdot a$$

Why do we have a subscript in the E_x expression? The energy in the x-direction? Energy is not supposed to have any direction, does it? Right. And not so right. We calculate kinetic energy based on velocities: velocities imply motion, and motion implies some direction. Likewise, potential energy is related to the position of some charge *vis-à-vis* some other charge: that implies some idea of direction too. That brings us to the next question: what is the energy concept here? Is E_x kinetic or potential? The shape of the integral suggests we are calculating potential energy – but we do so over a full *cycle*. We know the

---

[3] We are tempted to write cos(θ) and sin(θ) in boldface too because a **cos**(θ) and **sin**(θ) notation would remind the reader of the fact we are talking vector quantities here: mathematical objects that do not only have a magnitude but a direction too, and an origin that may or may not matter. However, we stick to the usual conventions. Note that the multiplication by the imaginary unit (*i*) – which amounts to a rotation by 90 degrees – ensures independence of the two force components.

[4] The two possible directions of the pointlike charge and the two possible directions of the force give us four situations, which reflect the four quadrants of the circle. This is why we broke up the integral into four different parts. The minus signs are explained by the reversal of the direction of the pointlike charge.

potential energy goes from 0 to some maximum at *a* and –*a*, and then back to zero. In-between, potential energy is converted into kinetic energy and vice versa. Hence, we are, effectively, calculating the total energy here.

What about E_y? We can calculate E_y in exactly the same way but, remember, the kinetic energy in the *y*-direction reaches a maximum when it reaches zero in the *x*-direction, and vice versa for the potential energy. We have a *phase* difference of 90 degrees. In our very first paper(s) on this[5], we introduced a metaphor, a *perpetuum mobile* combining *two* oscillators in a 90-degree angle: two springs or two pistons attached to some crankshaft. The inspiration came from a reflection on the optimum angle between the two pistons of a V-2 engine. When the angle between is equal to 90 degrees, then it is possible to perfectly balance the counterweight and the pistons, which ensures smoother travel.[6] The analogy can be extended to include two *pairs* of springs or pistons, in which case the springs or pistons in each pair would help drive each other. In either case, we have a beautiful interplay between linear and circular motion. In this interplay, energy is borrowed from one place and then returns to the other, cycle after cycle: while transferring kinetic and potential energy from one piston to the other[7], the crankshaft will rotate with a constant angular velocity: linear motion becomes circular motion, and vice versa.

What's the point? The point is: we can *not* just *add* E_x and E_y to get the *total* energy of the system: we'd be double-counting. $E = 2\cdot F\cdot a$ is the total energy. We can now combine this with the $F = m_\gamma\cdot a_c = m_\gamma\cdot a\cdot\omega^2 = m_e\cdot a\cdot\omega^2/2$ formula to get the following grand result:

$$E = 2Fa = 2m_\gamma a\omega^2 a = m_e a^2\omega^2$$

If we'd have some classical (non-relativistic) harmonic oscillator – think of a mass m going up and down at non-relativistic speeds – then its total energy would be equal to $E = ma^2\omega^2/2$. Here we get *twice* that value. It is a beautiful result.

Our calculation of the Compton radius combining the $c = a\cdot\omega$, $E = m\cdot c^2$ and $E = \hbar\cdot\omega = h\cdot f$ equations now makes perfect sense. We can re-write it as follows:

$$E = mc^2 = ma^2\omega^2 = ma^2\frac{E^2}{\hbar^2} \Leftrightarrow a = \sqrt{\frac{E}{m}\frac{\hbar^2}{E^2}} = \sqrt{c^2\frac{\hbar^2}{E^2}} = \frac{\hbar c}{E} = \frac{\hbar c}{mc^2} = \frac{\hbar}{mc} = r_C \approx 0.386\times 10^{-12}\ \text{m}$$

QED: Quod erat demonstrandum. 😊

[5] See, for example: http://vixra.org/abs/1709.0390.

[6] Ducati motorbike engines are 90-degree banked. Harley-Davidson engines are 45-degree V-twin engines. This gives the Harley its typical irregular sound. To be precise, what happens is this: a piston fires; the next piston fires at 315 degrees; there is a 405-degree gap; a piston fires; the next piston fires at 315 degrees; there is a 405-degree gap; etcetera. That's because the engine is four-stroke.

[7] Physicists will probably prefer a double-spring system as a metaphor – as opposed to a Ducati V-twin engine! The principle is the same, however: with permanently closed valves, the air inside the cylinder compresses and decompresses as the pistons move up and down. It provides, therefore, a restoring force. As such, it will store potential energy, just like a spring.

Kinetic versus potential energy

We have already highlighted how the total energy of the electron is divided over potential and kinetic energy. However, we should, perhaps, add a final remark here. If we think of the tangential velocity as a vector quantity, then we will write it as: $\boldsymbol{c} = \boldsymbol{v}_x + \boldsymbol{v}_y$. If we think of speed only – *magnitudes* rather than vector quantities – then we need to use Pythagorean Theorem: $c^2 = v_x^2 + v_y^2$.[8] The same is true for all the other vectors (and may lead to other interesting geometric interpretations of common formulas) but let's focus on these velocities for the time being. We can write the $c^2 = v_x^2 + v_y^2$ equation as:

$$m_\gamma c^2 = m_\gamma(v_x^2 + v_y^2) = m_e c^2/2$$

You'll say: so what? That's the logic of the model, right? It is. However, I find this simple formula quite intriguing: it's got the same shape as the non-relativistic formula for kinetic energy: $mv^2/2$. Our analysis was relativistically correct, but the circular motion – the idea of a two-dimensional oscillation – somehow seems to melt relativistic and non-relativistic formulas into one.

Calculating the electron force

We've calculated the known properties of an electron (e.g. spin and magnetic moment). Can we calculate the magnitude of that force? Of course, we can! We get it from the E = 2·F·*a* energy formula:

$$\mathrm{F} = \frac{\mathrm{E}}{2a} \approx \frac{8.187 \times 10^{-14}\ \mathrm{J}}{2 \cdot 0.386\ \times 10^{-12}\ \mathrm{m}} \approx 0.106\ \mathrm{N}$$

This force is equivalent to a force that gives a mass of about 106 *gram* (1 g = 10^{-3} kg) an acceleration of 1 m/s per second. This is *huge* at the sub-atomic scale. Because this is so enormous, we need to think about energy densities and, perhaps, wonder if general relativity comes into play. We will offer a few – very limited – reflections on that in the next section of this paper.

Introducing gravity

We calculated the force, and we found that it was huge. We can also calculate the *numerical* value of the field strength, and we should not be surprised that we get an equally humongous field strength:

$$E = \frac{F}{\mathrm{q_e}} \approx \frac{10.6 \times 10^{-2}\ \mathrm{N}}{1.6\ \times 10^{-19}\ \mathrm{C}} \approx 0.6625 \times 10^{18}\ \mathrm{N/C}$$

Just as a yardstick to compare, we may note that the most powerful man-made accelerators reach field strengths of the order of 10^9 N/C (1 GV/m) only. This is a billion times more. Hence, we may wonder if this value makes any sense at all. To answer that question, we can, perhaps, try to calculate some energy *density*. Using the classical formula, we get:

$$u = \epsilon_0 E^2 \approx 8.854 \times 10^{-12} \cdot (0.6625 \times 10^{18})^2 \frac{\mathrm{J}}{\mathrm{m^3}} = 3.9 \times 10^{24}\ \frac{\mathrm{J}}{\mathrm{m^3}}$$

---

[8] For some reason I cannot quite explain, I find the juxtaposition of these two formulas as weird as Euler's formula itself. In fact, they pretty much represent Euler's formula, because we can write it as $|e^{i\theta}| = \sqrt{\cos^2\theta + \sin^2\theta}$ or, alternatively, as $e^{i\theta} = \cos\theta + i \cdot \sin\theta$.

This amounts to about 43 kg per mm^3 (cubic *milli*meter). Is this a sensible value? Maybe. Maybe not. The rest mass of the electron is tiny, but then the *zbw* radius of an electron is also exceedingly small. It is very interesting to think about what might happen to the curvature of spacetime with such mass densities: perhaps our pointlike charge just goes round and round on a geodesic in its own (curved) space. We are not well-versed in general relativity and we can, therefore, only offer some general remarks here:

1. If we would pack all of the mass of an electron into a black hole, then the Schwarzschild formula gives us a radius that is equal to:

$$r_s = \frac{2\mathrm{Gm}}{c^2} \approx 1.35 \times 10^{-57}\mathrm{m}\ (meter)$$

This exceedingly small number has no relation whatsoever with the Compton radius. In fact, its scale has no relation with whatever distance one encounters in physics: it is *much* beyond the Planck scale, which is of the order of 10^{-35} meter and which, for reasons deep down in relativistic quantum mechanics, physicists consider to be the smallest possibly sensible distance scale.

2. We are intrigued, however, by suggestions that the Schwarzschild formula should not be used as it because an electron has angular momentum, a magnetic moment and other properties, perhaps, that do not apply when calculating, say, the Schwarzschild radius of the mass of a baseball. To be precise, we are particularly intrigued by models that suggest that, when incorporating the above-mentioned properties of an electron, the Compton radius might actually be the radius of an electron-sized black hole (Burinskii, 2008, 2016).[9]

The integration of gravity into this oscillator model will be our prime focus of research over the coming years. We totally concur with Dr. Burinskii's instinct here: the integration of gravity into the model may well provide "*the true path to unification of gravity with particle physics.*"[10]

Conclusions: the road to a realist interpretation of QM

We presented a very basic but viable 'mass without mass' model of an electron. The most intriguing and interesting aspect of the model is that it yields a realist common-sense interpretation of quantum physics. All pieces fall into place: we can understand the real and the imaginary part of the wavefunction as an oscillating electric and magnetic field. It is, likewise, possible to also analyze Schrödinger's wave equation as a diffusion equation for electromagnetic energy.[11]

[9] See: Alexander Burinskii, *The Dirac–Kerr–Newman electron*, 19 March 2008, https://arxiv.org/abs/hep-th/0507109. A more recent article of Mr. Burinskii (*New Path to Unification of Gravity with Particle Physics*, 2016, https://arxiv.org/abs/1701.01025, relates the model to more recent theories – most notably the "supersymmetric Higgs field" and the "Nielsen-Olesen model of dual string based on the Landau-Ginzburg (LG) field model.".

[10] See: Alexander Burinskii, *The weakness of gravity as an illusion hiding the true path to unification of gravity with particle physics*, Essay written for the Gravity Research Foundation, March 30, 2017

[11] See: Jean Louis Van Belle, *A Geometric Interpretation of Schrödinger's Wave Equation*, 12 December 2018 (http://vixra.org/abs/1812.0202) and Jean Louis Van Belle, *The Wavefunction as an Energy Propagation Mechanism*, 8 June 2018 (http://vixra.org/abs/1806.0106). While we still adhere to the basic intuition and results in these two papers, we would need to update them in light of our more recent updates and corrections to our interpretation.

The model is simple but complete. It should, therefore, be seen as scoring much better on *Occam's Razor* criterion than the current mainstream interpretation of quantum physics. We hope this model will be evaluated somewhat more positively by mainstream academics in the future, especially when complemented by more advanced mathematical techniques (such as Hestenes' geometric calculus, which does away with weird symmetries[12]) and when integrated with gravity (Burinskii's Kerr-Newman models of an electron, that is).

To conclude this paper, we present – side by side – the summary results for (i) the spin-only electron (most of which we derived here) and (ii) the orbital electron (Table 1).[13]

Table 1: 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 $n = 1, 2, \ldots$
$\mathrm{E} = \mathrm{m}c^2$	$\mathrm{E}_n = -\frac{1}{2}\frac{\alpha^2}{n^2}\mathrm{m}c^2 = -\frac{1}{n^2}\mathrm{E}_R$
$r = r_\mathrm{C} = \frac{\hbar}{\mathrm{m}c}$	$r_n = n^2 r_\mathrm{B} = \frac{n^2 r_\mathrm{C}}{\alpha} = \frac{n^2}{\alpha}\frac{\hbar}{\mathrm{m}c}$
$v = c$	$v_n = \frac{1}{n}\alpha c$
$\omega = \frac{v}{r} = c \cdot \frac{\mathrm{m}c}{\hbar} = \frac{\mathrm{E}}{\hbar}$	$\omega_n = \frac{v_n}{r_n} = \frac{\alpha^2}{n^3\hbar}\mathrm{m}c^2 = \frac{\frac{1}{n^2}\alpha^2\mathrm{m}c^2}{n\hbar}$
$\mathrm{L} = I \cdot \omega = \frac{1}{2} \cdot \mathrm{m} \cdot a^2 \cdot \omega = \frac{\mathrm{m}}{2} \cdot \frac{\hbar^2}{\mathrm{m}^2c^2}\frac{\mathrm{E}}{\hbar} = \frac{\hbar}{2}$	$\mathrm{L}_n = I \cdot \omega_n = n\hbar$
$\mu = \mathrm{I} \cdot \pi {r_\mathrm{C}}^2 = \frac{\mathrm{q_e}}{2\mathrm{m}}\hbar$	$\mu_n = \mathrm{I} \cdot \pi {r_n}^2 = \frac{\mathrm{q_e}}{2\mathrm{m}}n\hbar$
$\mathrm{g} = \frac{2\mathrm{m}}{\mathrm{q_e}}\frac{\mu}{\mathrm{L}} = 2$	$\mathrm{g}_n = \frac{2\mathrm{m}}{\mathrm{q_e}}\frac{\mu}{\mathrm{L}} = 1$

The basic results are all here: we can further develop this into a complete realist interpretation of QM. Our manuscript[14], for example, also explains what photons actually are, and how they interact with electrons. It also provides an alternative explanation of electron orbitals or, to be precise, a common-sense *physical explanation* of the wave equation and other so-called mysterious quantum-mechanical phenomena (anomalous magnetic moment, Mach-Zehnder interference, etcetera). In regard to the anomalous magnetic moment – the so-called *high-precision test* of mainstream quantum mechanics – we would like to draw the reader's attention to the interesting possibility that the anomalous magnetic moment of an electron might be explained by a very classical coupling between the spin and orbital moment (think of the Larmor precession of the electron in the Penning trap). It may, therefore, not be

[12] Also see: Jean Louis Van Belle, Philosophy and Physics, 7 June 2019 (http://vixra.org/abs/1906.0082).
[13] The reader may be surprised by this sudden introduction of a new model and the related formulas. We refer to our manuscript: Jean Louis Van Belle, *The Emperor Has No Clothes: A Realist Interpretation of Quantum Mechanics*, 21 April 2018 (http://vixra.org/abs/1901.0105).
[14] See reference above.

anomalous at all, and we shouldn't need quantum field theory to explain it.[15] In short, we think there is no mystery. It's all plain physics. The Emperor has no clothes.

What about quantum chromodynamics (QCD)? It is not the place here to expand on that. We will limit ourselves to the following question: why do we believe a force must be *mediated* by some particle – *gauge* bosons? This idea resembles the 19th-century *aether* theory: perhaps we don't need it. We don't need it in electromagnetic theory: Maxwell's Laws – augmented with the Planck-Einstein relation – will do. We also don't need it to model the strong force. The *quark-gluon* model – according to which quarks change color all of the time – does *not* come with any simplification as compared to a simpler *parton* model. However, we do not want to repeat ourselves here – or include too much in this simple paper – and we, therefore, refer the reader to other material.[16]

END

---

[15] Jean Louis Van Belle, *The Anomalous Magnetic Moment: Classical Calculations*, 11 June 2019 (http://vixra.org/abs/1906.0007).

[16] See, for example: Jean Louis Van Belle, *Smoking Gun Physics*, 21 June 2019 (http://vixra.org/abs/1907.0367).