A classical explanation of the scattering of photons by electrons

Jean Louis Van Belle, 13 December 2019

Summary

In this paper, we bring the *Zitterbewegung* electron model and our photon model together to provide a classical explanation of the scattering of photons by electrons. We understand electron-photon interference (the scattering of photons by electrons) as two electromagnetic oscillations interfering (classically) with each other. While developing the model, we offer some reflections on the Uncertainty Principle (Copenhagen interpretation of quantum mechanics). We conclude there is no need for it: God doesn't play dice..

Contents

Introduction: Feynman's thought experiment

What is uncertainty in quantum mechanics? How does it relate to the philosophical concepts of freedom and determinism? When discussing the philosophical implications of the Uncertainty Principle in quantum mechanics, Richard Feynman notes that, "*from a practical point of view*", we have "indeterminability in classical mechanics as well."[1] He gives the example of water splashing over a dam:

> "If water falls over a dam, it splashes. If we stand nearby, every now and then a drop will land on our nose. This appears to be completely random, yet such a behavior would be predicted by purely classical laws. The exact position of all the drops depends upon the precise wigglings of the water before it goes over the dam. How? The tiniest irregularities are magnified in falling, so that we get complete randomness. Obviously, we cannot really predict the position of the drops unless we know the motion of the water absolutely exactly."

While, from a practical point of view, it may effectively be impossible to know the motion of the water "absolutely exactly", the deeper question is: is it *theoretically* possible? In classical mechanics, we assume it is. In quantum mechanics, we assume it is *not*. Quoting Feynman once again, we may say "the Uncertainty Principle *protects* quantum mechanics." It is probably good to discuss the context in which he uses this phrase. He uses it in the context of a thought experiment. The thought experiment is a variant of the two-slit experiment. The set-up is shown below.[2]

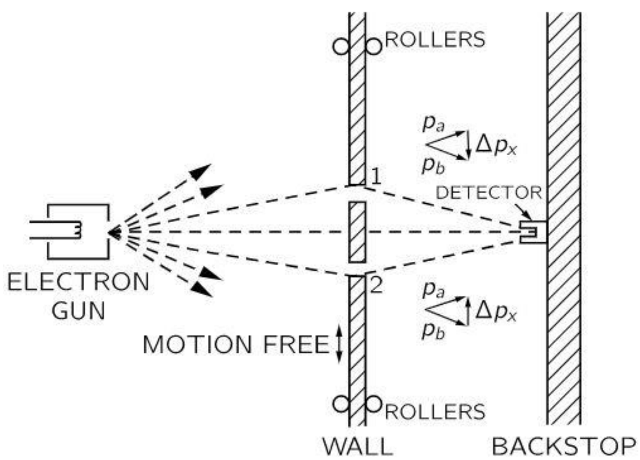

Figure 1: Feynman's thought experiment

Feynman's thought experiment is pretty much the same as the standard two-slit experiment, which you have probably studied *ad nauseam* (Feynman also starts his Lectures on Quantum Mechanics with it), except for the 'wall' with the two slits, which is now "mounted on rollers so that it can move freely up and down." Feynman now develops an argument which may trick us into thinking we might be able to beat the Uncertainty Principle:

> "By watching the motion of the plate carefully we can try to tell which hole an electron goes through. Imagine what happens when the detector is placed at $x = 0$. We would expect that an

[1] See: Feynman's Lectures, III-2-6 (https://www.feynmanlectures.caltech.edu/III_02.html#Ch2-S6).

[2] The illustration and much of the text has been borrowed from Feynman's introduction to his Lectures on Quantum Mechanics (https://www.feynmanlectures.caltech.edu/III_01.html#Ch1-S8).

> electron which passes through hole 1 must be deflected downward by the plate to reach the detector. Since the vertical component of the electron momentum is changed, the plate must recoil with an equal momentum in the opposite direction. The plate will get an upward kick. If the electron goes through the lower hole, the plate should feel a downward kick. It is clear that for every position of the detector, the momentum received by the plate will have a different value for a traversal via hole 1 than for a traversal via hole 2. So! Without disturbing the electrons at all, but just by watching the plate, we can tell which path the electron used."

Of course, Feynman only tells us this story to immediately refute it. He thinks we can't beat the Uncertainty Principle:

> "Now in order to do this it is necessary to know what the momentum of the screen is, before the electron goes through. So when we measure the momentum after the electron goes by, we can figure out how much the plate's momentum has changed. But remember, according to the uncertainty principle we cannot at the same time know the position of the plate with an arbitrary accuracy. But if we do not know exactly where the plate is, we cannot say precisely where the two holes are. They will be in a different place for every electron that goes through. This means that the center of our interference pattern will have a different location for each electron. The wiggles of the interference pattern will be smeared out. […]
>
> The uncertainty principle "protects" quantum mechanics. Heisenberg recognized that if it were possible to measure the momentum and the position simultaneously with a greater accuracy, the quantum mechanics would collapse. So he proposed that it must be impossible. Then people sat down and tried to figure out ways of doing it, and nobody could figure out a way to measure the position and the momentum of anything—a screen, an electron, a billiard ball, anything—with any greater accuracy. Quantum mechanics maintains its perilous but still correct existence."

As far as I am concerned, this is *not* Feynman at his best. It's Feynman at his worst. We should, first, note that Feynman implies we cannot position the plate on rollers at $x = 0$ so its momentum is zero as well. Secondly, it is quite non-sensical to describe an electron as some bullet that has some precise momentum in the x- and y-direction and, therefore, as something that would be deflected classically.

These thought experiments are not about the Uncertainty Principle "protecting" quantum physics: it's physicists protecting the Uncertainty Principle. Of course, one wonders: why would they do this? They are searching for the truth as well, don't they?

Maybe. Maybe not. Perhaps they feel quantum-mechanical indeterminism (as opposed to the statistical indeterminism in classical mechanics) is the very last place where God – or the Mystery, or whatever we cannot prove but happen to *believe* in – can hide.

The *Zitterbewegung* model of an electron

You may or may not have heard about this model. Erwin Schrödinger, who coined the term (*Zitterbewegung* refers to a trembling or shaking motion), 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)

We have fully developed the model in other papers, so we will not dwell on it too long here.[3] The *Zitterbewegung* interpretation of quantum mechanics models the electron as a pointlike electric *charge* in a circular orbit. Its tangential velocity is equal to the speed of light and, obviously, equals the product of the radius and the angular velocity: $v = a \cdot \omega = c$, as shown below. Hence, we think of the electron as a current ring.

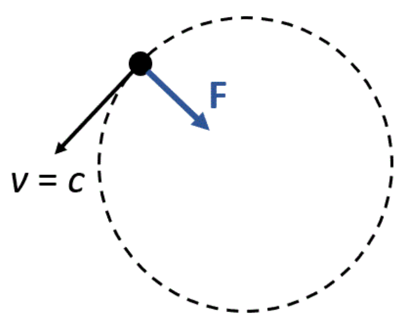

Figure 2: The electron as a current ring

If the tangential velocity is equal to the speed of light, then the *rest* mass of the pointlike charge (think of it as the hard core of the electron) 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 embodies Wheeler's idea of mass without mass. We should note that pointlike doesn't mean the charge itself has no dimension whatsoever: we think its size is equal to the *classical* electron radius. Why? Because it would explain the anomalous magnetic moment of an electron. However, we talked about this elsewhere, so we do not want to repeat ourselves here.[4] Equally (if not more) importantly, we also get that radius out of electron-photon scattering experiments (we will say more about that later). Just take a mental note here: if we say pointlike, it means we cannot analyze the pointlike charge any further: it has, therefore, no structure. It does *not* imply this charge has no dimension whatsoever. In fact, we think objects that have no dimension whatsoever do not *exist*.

Let us get back to the electron itself. The electron as a whole is, obviously, *not* pointlike: its structure is that high-frequency oscillatory motion of small amplitude that comes out of Dirac's equation. That's why

[3] See, for example, our *Mass without Mass* paper (http://vixra.org/abs/1908.0225).

[4] See our *Classical Calculations of the Anomalous Magnetic Moment* (http://vixra.org/abs/1906.0007).

the electron has two radii: the Thomson radius (or classical electron radius) and the Compton radius. We can easily calculate the Compton radius. 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:

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

This value has been confirmed *experimentally*. Moreover, it's probably one of the most precise measurement in physics. The calculation is, therefore, astonishingly beautiful. Why? Because it is so simple. Having said that, its *physical* interpretation is, obviously, *not* so simple. We offer following remarks on this:

1. Each *cycle* of the *Zitterbewegung* packs (i) one unit of physical *action* (h) and (ii) the electron's energy ($E = mc^2$). Now, the concept of physical action (*Wirkung*) might not be very familiar nor intuitive to the average student of physics and that, surely, its association with a fundamental *cycle* in Nature must be even less so. We will let the reader think about this, but it is quite significant that, since the revision of SI units (2018-2019), the American National Institute of Standards and Technology prefers to express the CODATA value of Planck's constant (h) in J/Hz rather than N·m·s, even if both are equivalent.[5]

While we let this sink in, we can quickly calculate the cycle *time* from the Planck-Einstein relation, which we like to write as $E/T = h$. The $T = 1/f$ in this equation is, effectively, the cycle time, which we can thus calculate as equal to:

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

That's a *very* small amount of time: as Dirac notes, we can*not* directly verify this by experiment.[6] We hope the reader 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, and why NIST's preference for the J/Hz dimension for h makes a lot of sense:

$$h = \mathrm{E}\cdot\mathrm{T} = \mathrm{h}\cdot f\cdot\mathrm{T} = \mathrm{h}\cdot f/f = h$$

We hope the remarks above have not dazzled the reader. If so, the following remarks may be easier to digest.

2. What is the *nature* of this fundamental oscillation? Indeed, to keep an object with some momentum in a circular orbit, a centripetal force is needed – as shown in Figure 2. What is the nature of this force? Because the force can only grab onto the charge, it must be electromagnetic. In Hestenes' interpretation of the *Zitterbewegung* model[7], the circular current creates a magnetic flux through the ring which keeps

[5] See https://physics.nist.gov/cgi-bin/cuu/Value?h.

[6] 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.

[7] See, for example: D. Hestenes, Found. Physics., Vol. 20, No. 10, (1990) 1213–1232, *The Zitterbewegung Interpretation of Quantum Mechanics*, http://geocalc.clas.asu.edu/pdf/ZBW_I_QM.pdf, and D. Hestenes, 19 February 2008, *Zitterbewegung in Quantum Mechanics – a research program*, https://arxiv.org/pdf/0802.2728.pdf.

the current going – just like in a superconducting ring. This interpretation has one problem: there is no real material ring to hold and guide our charge in free space, so what keeps this thing *tuned*? We must be honest and admit we have no answer to this question. However, that should not prevent us from further exploring what might or might not be going on. To do so, we will present some more calculations. Let us start by calculating the centripetal acceleration: it's equal to:

$$a_c = v_t^2/a = a\cdot\omega^2$$

The reader should note this formula is relativistically correct. Indeed, 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, here we run into problems: what is the mass of our pointlike charge? We said its (rest) mass was zero: it only acquires mass because it moves at the velocity of light. If m_0 is equal to zero, then what should we do with the relativistic $m = \gamma m_0$ formula? A multiplication with zero yields zero—*always*, doesn't it? […] Well… No. 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?

At this point, we need to talk about the concept of the *effective* mass of the pointlike charge. Again, we have done that elsewhere[8] and so we won't repeat ourselves here. We will just insert a summary of our approach, calculations and the key results.

The electron as a two-dimensional electromagnetic oscillation

Let us denote it the effective mass of our pointlike charge as $m_\gamma = \gamma m_0$. The subscript (γ) in m_γ refers to the Lorentz factor, of course. What is its value? of m_γ? It should not be zero, and it should also not be infinity. In addition, it would also be quite sensible to think that m_γ must be smaller than the rest mass of the electron m_e. Indeed, it cannot be larger because the energy of the oscillation would then be larger than $E = mc^2$. So what could it be? Rather than guessing, we may want to remind ourselves that we know the angular momentum of the electron: $L = \hbar/2$. We have calculated it using the $L = I\cdot\omega$ formula and using an educated guess for the moment of inertia ($I = m\cdot a^2/2$)[9], 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. $p = m_\gamma c$

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

[8] See the above-mentioned *Mass without Mass* paper (http://vixra.org/abs/1908.0225) as well our *Electron as a Harmonic Electromagnetic Oscillator* paper (http://vixra.org/abs/1905.0521).
[9] See the references above.

This is a nice result, because it explains the previously mysterious concept of the effective mass of an electron using common-sense calculations. Let us summarize the result in plain text: 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 centripetal force F as $F = m \cdot a_c = m \cdot a \cdot \omega^2$ as:

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

All that remains to be done now is to deconstruct and analyze the centripetal force **F** as the sum of two force components. In other words, we think of the circular motion of our pointlike charge as the sum of two perpendicular oscillations. Because the two oscillations are perpendicular and, therefore, independent, we can add the energy of both oscillations and combine the result with the $F = m_\gamma \cdot a_c = m_\gamma \cdot a \cdot \omega^2 = m_e \cdot a \cdot \omega^2/2$ above to get Einstein's mass-energy equivalence relation[10]:

$$E = 2 \cdot F \cdot a = 2 \cdot m_\gamma \cdot a \cdot \omega^2 a = m_e \cdot a^2 \cdot \omega^2 = m_e \cdot c^2$$

The reader who skipped through the rather dense text and calculations should not worry that he will not be able to understand what follows. We only request the reader to try to imagine the electron as a two-dimensional electromagnetic oscillation driving a pointlike electric charge. The whirling around of the pointlike charge, in turn, is what keeps this electromagnetic oscillation going.

Electron-photon interference: Thomson and Compton scattering

So how does it work, *exactly*? At this point, we should probably say a few words about Dirac's reference to the "law of scattering of light by an electron", and how the *Zitterbewegung* model might explain it.

The reader will, without any doubt, know that photons may be scattered elastically or inelastically when interfering with an electron: 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. Of course, we are talking a limiting case here, which is valid as long as the photon energy is much smaller than the mass energy of the particle.[11]

[10] Energy is a force over a distance and the calculations, therefore, involve integrals which, although simple, we will not write down here. We refer the interested reader, once again, to our *Mass without Mass* paper for more detail. (http://vixra.org/abs/1908.0225).

[11] The Wikipedia article on Thomson scattering correctly describes Thomson scattering as "the low-energy limit of Compton scattering:" (see: https://en.wikipedia.org/wiki/Thomson_scattering, accessed on 13 December 2019).

The terms elastic and inelastic suggest a duality which is not really there. We think of the photon itself as an electromagnetic oscillation that *interferes* with the two-dimensional oscillation. At this point, we should introduce the photon model.

Electron-photon interference: the photon model

In order to understand our (classical) explanation of electron-photon interference as the interference of two electromagnetic oscillations, we should explain the photon model. In order to do so, we should remind ourselves that photons are emitted (and absorbed) by atoms. We described this process elsewhere[12] and, hence, we will limit ourselves to an overview of the basics of the model.

The Bohr orbitals are separated by a amount of *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 Rydberg formula (see above). To focus our thinking, let us consider the transition from the second to the first level, for which the $1/1^2 - 1/2^2$ is equal 0.75. Hence, the photon energy should be equal to $(0.75)\cdot E_R \approx 10.2$ eV.[13] Now, if the total action is equal to *h*, then the cycle time T can be calculated as:

$$\mathrm{E} \cdot \mathrm{T} = h \Leftrightarrow \mathrm{T} = \frac{h}{\mathrm{E}} \approx \frac{4.135 \times 10^{-15}\,\mathrm{eV} \cdot \mathrm{s}}{10.2\ \mathrm{eV}} \approx 0.4 \times 10^{-15}\ \mathrm{s}$$

This corresponds to a wave train with a length of $(3\times10^{8}\ \mathrm{m/s})\cdot(0.4\times10^{-15}\ \mathrm{s}) = 122$ nm. That is the size of a large molecule and it is, therefore, much more reasonable than the length of the wave trains we get when thinking of transients using the supposed Q of an atomic oscillator.[14] In fact, this length is *exactly* equal to the wavelength $\lambda = c/f = c\cdot\mathrm{T} = hc/\mathrm{E}$.

What picture of the photon are we getting here? Because of the angular momentum, we will probably want to think of it as a circularly polarized wave, which we may represent by the elementary wavefunction, as shown below.[15] We call this interpretation of the wavefunction the *one-cycle photon*: the wavefunction represents the rotating electric field vector itself or, remembering the $\mathrm{F} = q_e\mathrm{E}$ equation, the force field.

---

[12] See our *Classical Quantum Theory of Light* (http://vixra.org/abs/1906.0200).

[13] This is short-wave ultraviolet light (UV-C). It is the light that is used to purify water, food or even air. It kills or inactivate microorganisms by destroying nucleic acids and disrupting their DNA. It is, therefore, harmful. The ozone layer of our atmosphere blocks most of it.

[14] In one of his famous *Lectures* (I-32-3), Feynman thinks about a sodium atom, which emits and absorbs sodium light, of course. Based on various assumptions – assumption that make sense in the context of the blackbody radiation model but *not* in the context of the Bohr model – he gets a Q of about 5×10^{7}. Now, the frequency of sodium light is about 500 THz (500×10^{12} oscillations per second). Hence, the *decay time* of the radiation is of the order of 10^{-8} seconds. So that means that, after 5×10^{7} oscillations, the amplitude will have died by a factor $1/e \approx 0.37$. That seems to be very short, but it still makes for 5 million oscillations and, because the wavelength of sodium light is about 600 nm (600×10^{-9} meter), we get a wave train with a considerable length: $(5\times10^{6})\cdot(600\times10^{-9}$ meter) = 3 meter. *Surely you're joking, Mr. Feynman!* A photon with a length of 3 meter – or longer? While one might argue that relativity theory saves us here (relativistic length contraction should cause this length to reduce to zero as the wave train zips by at the speed of light), this just doesn't feel right – especially when one takes a closer look at the assumptions behind.

[15] Note that the wave could be either left- or right-handed.

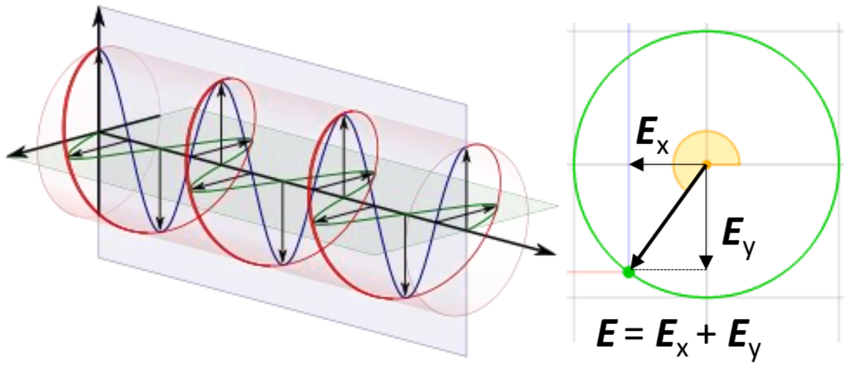

Figure 3: The one-cycle photon

It is a delightfully simple model: the photon is a circularly polarized electromagnetic oscillation traveling through space and time, which packs one unit of angular momentum ($\hbar$) or – which amounts to the same, one unit of physical action (h). This gives us an equally delightful interpretation of the Planck-Einstein relation (f = 1/T = E/h) and we can, of course, 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 $\mathrm{E} = \mathrm{m}c^2$ mass-energy equivalence relation can be written as p = mc = E/c for the photon. The two equations are, therefore, wonderfully consistent:

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

In previous papers[16], we show how to calculate the strength of the electric field (E) as a function of the photon's energy (E_γ). The field strength is the force per unit charge which, we should remind the reader, is the *coulomb* – *not* the electron charge. Dropping the subscript (γ), we get a delightfully simple formula for the strength of the electric field vector for a photon[17]:

$$E = \frac{\frac{2\pi hc}{\lambda^2}}{1} = \frac{2\pi hc}{\lambda^2} = \frac{2\pi \mathrm{E}}{\lambda} \left(\frac{N}{C}\right)$$

[16] See, for example, our *Classical Quantum Theory of Light* (http://vixra.org/abs/1906.0200).

[17] The E and E symbols should not be confused. E is the magnitude of the electric field vector and E is the energy of the photon. We hope the italics (E) – and the context of the formula, of course ! – will be sufficient to distinguish the electric field vector (E) from the energy (E).

Let us calculate its value for our 10.2 eV photon. We should, of course, express the photon energy in SI units here:

$$E \approx \frac{2\pi \cdot 1.634 \times 10^{-18}\, J}{122 \times 10^{-9}\, m \cdot C} \approx 84 \times 10^{-12}\mathrm{N/C}$$

This seems pretty reasonable – especially in light of our calculations of the electromagnetic field strength inside the electron, for which we got a humongous value[18]:

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

This huge value should not surprise us. We get the following value for the internal current of the electron:

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

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:

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

We could do some more calculations, but we will let the matter rest for the time being. The point is: the *Zitterbewegung* electron and our one-cycle photon model are intuitive and make sense, because we can now understand electron-photon interference (the scattering of photons by electrons) as two electromagnetic oscillations interfering with each other.

Conclusions

We admit we did not work out the exact *mechanics* of what happens here. The energy of the incident photon – as an electromagnetic oscillation, that is – seems to be temporarily absorbed by the electron and, hence, the electron is, therefore, in a state of non-equilibrium. As it returns to equilibrium, the electron emits some of the excess energy as a new photon, and the remainder gives the electron as a whole some additional momentum. We are confident that people who are smarter than us will be able to detail how things might be happening *exactly*.

The point here is: there is no need for the Uncertainty Principle: God doesn't play dice.

Jean Louis Van Belle, 13 December 2019

[18] See our *Mass without Mass* paper for more details (http://vixra.org/abs/1908.0225).