Relativity and light

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Summary: This paper adds some thoughts on relativity theory and geometry to our one-cycle photon model. We basically highlight what we should think of as being relative in this model (energy, wavelength, and the related force/field values), as opposed to what is absolute (the geometry of spacetime and the geometry of the photon).

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Of all of the foundational contributions to physics, Einstein's special relativity theory may well be the single most important one. Einstein's own introduction to is, perhaps, a bit lengthy but should probably be quoted in any explanation of the basics of the theory:

> "It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated. But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case."[1]

This makes it abundantly clear that what Einstein actually tries to explain in his groundbreaking article[2] is, perhaps, not the relativity of space and time, but the relativity of electric and magnetic fields. The *Great Teacher*, Richard Feynman[3], offers an excellent presentation of this in his *Lectures* on electromagnetism but, unfortunately, more as some digression as part of a larger argument than as a foundational think piece. We will just quote it and let the reader explore it if needed:

> "When we said that the magnetic force on a charge was proportional to its velocity, you may have wondered: "What velocity? With respect to which reference frame?" It is, in fact, clear from the definition of ***B*** given at the beginning of this chapter that what this vector is will depend on what we choose as a reference frame for our specification of the velocity of charges. But we have said nothing about which is the proper frame for specifying the magnetic field. It turns out that any inertial frame will do. We will also see that ***magnetism and electricity are not independent things***—that ***they should always be taken together as one complete electromagnetic field***. Although in the static case Maxwell's equations separate into two distinct pairs, one pair for electricity and one pair for magnetism, with no apparent connection between the two fields, nevertheless, in nature itself there is a very intimate relationship between them that arises from the principle of relativity. *Historically, the principle of relativity was discovered after Maxwell's equations. It was, in fact, the study of electricity and magnetism which led ultimately to Einstein's discovery of his principle of relativity*."[4]

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[1] Quoted from http://hermes.ffn.ub.es/luisnavarro/nuevo_maletin/Einstein_1905_relativity.pdf.

[2] As you probably know, this paper was one of four papers from his hand that were published in the *Annalen der Physik* journal in 1905, which are, therefore, referred to as Einstein's *Annus Mirabilus* papers.

[3] The epithet is from Bill Gates, but is disputed. See: https://mathblog.com/was-richard-feynman-a-great-teacher/.

[4] Richard Feynman, *Lectures on Physics*, II-13-6, *The relativity of magnetic and electric fields*. Italics and boldface are mine.

Now that we are here, I would like to introduce a symbol which I'll need later: ***Ɛ***. I will use it to denote the combined *electromagnetic* field that Feynman mentions above.[5] You will not find it in any physics textbook because the idea is not very useful in calculations. It combines the ideas of the electric and magnetic field respectively which – in line with general usage – we denote as ***E*** and ***B***. We can now write the electromagnetic force ***F*** – which is usually referred to as the *Lorentz* force, in honor of the great Dutch scientists who inspired so much and so many – on some electric charge q as[6]:

$$\boldsymbol{F} = q\boldsymbol{E} + q(\boldsymbol{v}\times\boldsymbol{B}) = q(\boldsymbol{E} + \boldsymbol{v}\times\boldsymbol{B}) = q\boldsymbol{\mathcal{E}}$$

We know a field is generally defined as the force per unit charge. What is the unit charge? It is *not* the charge of the electron (or the proton) – that is the *elementary* charge, which is something else – but the two concepts are, obviously, closely related. To be precise, the unit charge is the *coulomb* (C), and under the 2019 redefinition of the SI base units, the coulomb is now defined in terms of the elementary charge, which is the charge of the proton (or, what amounts to the same, its negative: the charge of the electron). Under this redefinition, which took effect on 20 May 2019, the elementary charge has now effectively been *defined* as $1.602176634\times10^{-19}$ coulombs, *exactly*—and vice versa: the coulomb is the charge of $1/1.602176634\times10^{-19}$ protons, *exactly*.

This value is, obviously, not relative. It is a fundamental constant of Nature, just like *c* or *h*. To be precise, its value does *not* depend on the reference frame. In contrast, the values we'll measure for ***E*** and ***B*** and, hence, for ***F*** and ***Ɛ*** will be relative and dependent on our motion relative to the charge. We do want to introduce four-vector algebra here but just note that (electric) charge is *not* relative and that, therefore, the $\boldsymbol{F}/\boldsymbol{\mathcal{E}} = q$ *ratio* should also *not* depend on the reference frame: it should be the same in *any* reference frame. We will use this later: just take a mental note of it as for now.

To conclude this section, I should probably say a few words about the concept of a field. Both physicists and philosophers alike tend to write volumes about that, usually noting that what is relative can, somehow, not be real and that we, therefore, should try to find "some kind of gear wheels", or "something that can transmit the force."[7] Most physicists will dismiss that as rubbish but, unfortunately, then proceed to discuss what might or might not be going on inside of the nucleus of an atom and suddenly bring back the whole idea of 'gear wheels' through the back door: think of 'messenger particles' such as virtual photons or gluons here. I'll be clear: I think of that as rubbish too.

I readily admit that the concept of a field is very mysterious. At the same time, it's not all that difficult either, is it? We just need to try imagining ***a force in the absence of a charge to act on.*** That's all. I feel we should not try to talk it away from that concept by introducing even more mysterious concepts. Unfortunately, such unnecessary multiplication of concepts is exactly what most of mainstream quantum physicists seems to be busying themselves with.

[5] As for the symbol, Wikipedia refers to it as a Latin epsilon or open e (majuscule: Ɛ, minuscule: ɛ). It is a letter of what is referred to as the extended Latin alphabet based on the lowercase of the Greek letter epsilon (ε). It's apparently in use in some Niger–Congo languages, which is why it's included in the African reference alphabet.
[6] A force always acts on a charge. In this case, it acts on an *electric* charge. When entering the realm of the nucleus, we will need to think of other forces and, hence, other charges. As for now, however, no confusion is possible and, hence, we will use the subscript e (in q_e, for example) to denote the elementary or *electron* charge.
[7] I quote from the interesting and, at the same time, fairly concise treatment of fields by Richard Feynman: see his *Lectures*, II-1-5, *What are the fields?*

Einstein's theorems

None of the words in 'special relativity theory' are very appropriate. First, the theory has been generally accepted—not only by scientists but by 'the general public' as well. It, therefore, feels very strange – to me, at least – to simply refer to it as just one of the (many) *theories* in physics—especially in light of the fact that most other theories (think of quantum field theory or the quark hypothesis, for example[8]) cannot be said to be equally well established. Second, special relativity theory deals with very common concepts – time, distance, mass and energy – and should, therefore, not be thought of as being *special*. On the contrary: it is *universally* applicable, unlike general relativity theory, which deals with one force only (gravity)—trying, in fact, to explain that it is, perhaps, *not* a force.[9]

Finally – and most importantly, in my not-so-humble view – it is actually centered around what is *absolute*: the speed of light, first and foremost, and then all of Nature's fundamental laws as we know them—laws that relate the speed of light to other *absolute* natural and mathematical constants.[10] As such, I more like to think that Einstein's so-called special relativity theory firmly established (1) Lorentz transformations, (2) the Planck-Einstein relation – which I prefer to write as $h = \mathrm{E}\cdot\mathrm{T}$ rather than as $\mathrm{E} = h\cdot f$ for reasons I'll explain later[11]) and – equally important – (3) the $\mathrm{E} = \mathrm{m}\cdot c^2$ mass-energy equivalence relation as fundamental *theorems*.[12]

As I am introducing some of the more fundamental formulas here, I would like to introduce one or two more. Think of the concept of a photon or – something I'd like you to store as a mental concept – the weird idea of a pointlike charge: the *naked* charge, with no other properties but its *charge* (electric, strong, color, or whatever other *charge* a force could possibly act upon). Something with *zero* rest mass:

[8] For clarity, I am aware some Nobel Prizes have been awarded lending very much credibility to these and other 'hypotheses' or 'theories.' Another example is the hypothesis of the all-pervading Higgs field, which also got a Nobel Prize. A Nobel Prize in Physics means a lot. However, it should not necessarily be equated with absolute truth: the award of a Nobel Prize only reflect rather general acceptance of a new idea by academics. Many of the ideas in this paper are not *generally* accepted. They represent a minority interpretation of quantum mechanics.

[9] We may or may not come back to this. At this point, I only want to flag that – despite its name – 'general' relativity theory is – in many ways – far more special than 'special' relativity theory. However, we should avoid getting lost in philosophical nitty-gritty so let's get on with the argument.

[10] Following the introduction to his article, Einstein himself refers to the 'principle of relativity' as follows: "Examples of this sort [i.e. the relativity of electric and magnetic fields], together with the unsuccessful attempts to discover any motion of the earth relatively to the 'light medium', suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good. We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate, which is only apparently irreconcilable with the former, namely, that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies."

[11] As for now, just note frequency and cycle time are each other's inverse: $\mathrm{T} = 1/f$. We will shortly talk about wavelengths, hence – for light – you should remember the elementary $v = c = f\cdot\lambda = f/\mathrm{T} \Leftrightarrow \lambda = c/f = c\cdot\mathrm{T}$ formula.

[12] I invite you to look up the definition of a theorem: a theorem is usually *not* self-evident, but allows one to develop a theory based on a number of very elementary propositions, which is what we want to do here.

all of the energy is its motion—in one or more dimensions.[13] We are told such things will move at the speed of light[14] and, hence, their *momentum* is equal to p = m·*c*. Inserting this p = m·*c* equation in the E = m·c^2 mass-energy equivalence relation, and combining it with the Planck-Einstein relation gives us the second[15] *de Broglie* relation: $E = m \cdot c^2 = p \cdot c = h \cdot f \Leftrightarrow c/f = \lambda = h/p \Leftrightarrow h = p \cdot \lambda$.

I mentioned I don't like to refer to Einstein's *theorems* as 'theory' because they have been generally accepted but, of course, it should not be about acceptance: society accepts many weird things. A more objective statement might be this: *no experiment so far* – and there have been many – *can be interpreted as a disproof of its conclusions*. To paraphrase Karl Popper, who is, arguably, one of the most critical philosophers of science[16], Einstein's theory is one of the very few think pieces that has not been falsified, yet. Personally, I think the theory is *true* but – following Popper – I have to admit such statement can only qualify as some *belief* or some metaphysical and, therefore, un-scientific *claim*.

Understanding relativity

It probably sounds arrogant, but I think few people – if any – truly *understand* relativity. It is, therefore, quite remarkable that even fewer people – except people whom we would consider to be unscientific – would challenge it, or dare to think someone will, one day, be able to prove Einstein's *logic* was wrong. As such, Einstein's theory is, effectively, one of science's greatest advances: (almost) no one understands it[17], but (almost) everyone accepts it as true. It is a weird thing: I find Einstein's *logic* in his 1905 article on special relativity[18] irrefutable but, at the same, I do dare to say that the *interpretation* of the key concepts and relativistic equations is still subject to discussion and debate. To be precise, I think it is fair to say that the *nature* of relativistic length contraction, time dilation – and, even more

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[13] We usually think of motion as being linear (one-dimensional) but I invite you to think of more complicated motions, such as oscillations in one, two or three dimensions. Four dimensions? No. Real space is three-dimensional. Don't try to think of things that cannot exist.

[14] The idea here is that *any* force – no matter how small – will cause an infinite acceleration according to the (relativistically) correct force law $F = m_v \cdot a$, which becomes $F = m_0 \cdot a$ for $v = 0$. Now, if m_0 is equal to zero, then a must be equal to infinity to yield some positive (non-zero and finite) value for F. The idea is *mathematically* correct but encapsulates all of the problems that are associated with a philosophical and physical interpretation of what a photon – or any elementary particle (our electron model is also based on the idea of a pointlike charge with zero *rest* mass whizzing around some center) – might actually *be*. We will come back to this.

[15] The first *de Broglie* relation is the Planck-Einstein relation.

[16] I originally wanted to label Popper as *the* most critical philosopher of science, but if you'd consider nihilists and cynics to be 'philosophers of science' too, then we should think of their 'philosophy' as being even more critical than falsificationist methodology. Having said this, I do not think of nihilism or cynicism as a logical method. Popper may not have offered much in terms of deciding of what may or may not be *true*, but I agree he did offer "a clear criterion that distinguishes scientific theories from metaphysical or mythological claims." For a good overview of Popper's life, interest and thought, see: https://www.iep.utm.edu/pop-sci/

[17] Believing the equations are, somehow, true, and accepting all of the implications does not amount to "understanding things the way we would like to." I am paraphrasing Richard Feynman's quote on understanding atomic behavior (or quantum physics, in general) here: "It appears peculiar and mysterious to everyone—both to the novice and experienced physicists. *Even the experts do not understand it the way they would like to.*"

[18] His article on special relativity was titled "*Zur Elektrodynamik bewegter Körper*", which means: *on the electrodynamics of moving bodies*. It is *not* an easy read, but a very worthwhile one (you can *google* an English translation of it). As you probably know, this paper was one of not less than four revolutionary papers from his hand that were published in the *Annalen der Physik* journal in the same year (1905). They are, therefore, collectively referred to as Einstein's *Annus Mirabilus* papers.

importantly – the *nature* of relativistic mass is not well understood—if at all. In fact, while no one questions the relativistic force equation – which, for convenience, we will reproduce a bit further – relativistic length contraction and time dilation are, effectively, still very much the subject of interpretational inquiries. To illustrate his, we may, perhaps, mention the introduction to an interesting article in this regard:

> "Recent advances in the theory of electromagnetic retardation have made it possible to derive the basic equations of the special relativity theory and to duplicate the most important practical results of this theory without using the concepts of relativistic length contraction and time dilation. Thus the reality of these concepts appears to be questionable. It is imperative therefore to reexamine the experimental evidence supporting these concepts. The calculations presented in this paper show that some of the experiments allegedly proving the reality of length contraction and time dilation can be unambiguously interpreted as manifestations of velocity-dependent dynamical interactions taking place within the systems involved in the experiments rather than as manifestations of length contraction or time dilation."[19]

We have not read analyzed these articles and papers in detail and, hence, we will refrain from making comments. We only note that the fundamental force equation involves relativistic mass only. Indeed, combining (1) Newton's force law ($\boldsymbol{F} = \mathrm{d}\mathbf{p}/\mathrm{d}t$), (2) the relativistic mass concept ($\mathrm{m}_v = \gamma\mathrm{m}_0$) and (3) the electromagnetic force law ($\boldsymbol{F} = \mathrm{q}\boldsymbol{E} + \mathrm{q}(\boldsymbol{v}\times\boldsymbol{B}) = \mathrm{q}\boldsymbol{\mathcal{E}}$), we get:

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[\frac{\mathrm{m}_0 \cdot \boldsymbol{v}}{\sqrt{1 - v^2/c^2}}\right] = \mathrm{q}(\boldsymbol{E} + \boldsymbol{v}\times\boldsymbol{B}) = \mathrm{q}\boldsymbol{\mathcal{E}}$$

There is, effectively, no need to think of relativistic length contraction or time dilation here. We will, therefore, not comment on these two concepts. In contrast, we do want to think some more about Einstein's first theorem: the *absoluteness* of the speed of light as one of Nature's fundamental constants. It is good to remind ourselves that this is a *very* weird thing, indeed! As Feynman puts it, with his usual disdain for the philosophers:

> "One will find few philosophers who will calmly state that it is self-evident that if light goes 186,000 mi/sec inside a car, and the car is going 100,000 mi/sec past an observer on the ground, that the light also goes 186,000 mi/sec past the observer on the ground."[20]

Because you are reading this, we must assume that you are already familiar with the basic *results* and relativistic *equations* that come out of this astonishing *fact*, which are the three things we mentioned above: relativistic length contraction, time dilation and relativistic mass—including the *caveats* on actual interpretation of these concepts. In fact, we must assume you are so familiar with these concepts that, by now, you may have accepted we do not really *understand* these things: we simply *accept* them as being, somehow, *true*—despite being as astonished as the philosophers, or even more so because, to paraphrase Feynman once more, we are *not* like "these philosophers, who are always with us, struggling

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[19] Oleg D. Jefimenko, 1998, *On the Experimental Proofs of Relativistic Length Contraction and Time Dilation*, Z. Naturforsch. 53a, 977-982 (https://www.degruyter.com/downloadpdf/j/zna.1998.53.issue-12/zna-1998-1208/zna-1998-1208.pdf).

[20] Richard Feynman, *Lectures on Physics*, p. I-16-2.

in the periphery to try to tell us something, but never really understanding the subtleties and depths of the problem."[21]

Let's go back to the light. We know the light beam in the car will consist of *photons*: light *quanta*, or *particles* of light—but we'd better talk of wavicles or use some other innovative term, because particles can refer to (almost) anything in physics, and so we should probably think of the term as being non-precise and, therefore, non-scientific. Einstein studied these light quanta too, and actually got his Nobel Prize in Physics for the photoelectric effect—*not* for his relativity theory.[22] So what *are* these photons?

We mentioned we don't think the term 'particle' is accurate and, therefore, useful. Willis Lamb, another Nobel Prize winner[23], went much further and actually claimed that even the concept of a photon is a "bad concept" with "no scientific justification" and that it is, therefore "high time to give up its use."[24] He wrote this when he was over 80 years old and, hence, we attribute the exaggerated boldness in this statement to old age. Having said that, we do acknowledge the point he wanted to make: we should think of photons as an electromagnetic *wave*, rather than as a particle. At the same time, electromagnetic radiation does come in packets, and there is no reason whatsoever to not refer to these as photons. Even if we do not want to think of these photons as, somehow, being 'particle-like', they do have momentum and energy, which are properties one does usually associate with particles.

More importantly, they come in *discrete* lumps. In short, they are, effectively, the *quanta* of light. Einstein phrased this as follows:

> "Energy, during the propagation of a ray of light, is not continuously distributed over steadily increasing spaces, but it consists of a finite number of energy quanta localised at points in space, moving without dividing and capable of being absorbed or generated only as entities."[25]

In case you wonder, the term 'photon' is said to combine the Greek *phōs* or *phōt,* which just means 'light', and the ending of the term 'electron'. However, if this is correct, then we should, perhaps, refer to it as a 'phot*r*on.'

The single most important difference between photons and proper particles – we could call them *matter*-particles but that's also confusing – is that photons do *not* carry any charge. All other *matter* as we know it, carry (electric) charge—think of protons, electrons or even neutrons[26] here: photons do *not*.[27] That's why 'photon' sounds better than 'photron'—to me, at least. But, if it is *not* charge, then

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[21] Richard Feynman, *Lectures on Physics*, p. I-16-1.
[22] Back in 2012, astronomy journalist Stuart Clark wrote a rather brilliant and oft-quoted article on that for the Guardian newspaper. See: https://www.theguardian.com/science/across-the-universe/2012/oct/08/einstein-nobel-prize-relativity. We warmly recommend reading it!
[23] You may or may not have heard of the so-called Lamb shift, which is a tiny energy difference between the $^2S_{1/2}$ and $^2P_{1/2}$ orbitals in the hydrogen atom. See: https://en.wikipedia.org/wiki/Lamb_shift.
[24] W.E. Lamb, Jr., *Anti-Photon*, in: Appl. Phys. B 60, 77-84 (1995).
[25] Quoted from Wikipedia's entry on Einstein's *Annus Mirabilis* papers.
[26] Neutrons are neutral but they do have a measurable magnetic moment. Hence, we think neutrons must, somehow, combine positive and negative charge. We will come back to this later.
[27] Some authors are popularizing the idea that a photon would, somehow, combine both negative and positive charge. See, for example, Richard Gauthier (https://richardgauthier.academia.edu/research). This idea is intuitively attractive because of the phenomenon of electron-positron pair production out of photons. However, we do not concur with the idea: pair production requires the presence of a nucleus and we, therefore, think something else is

what defines a photon as a discrete 'particle' or 'packet' of energy? The (preliminary) answer is: Planck's quantum of action.[28] The photon's energy and wavelength are both *relative* but they are related through that other fundamental constant in nature: *h* or, in its so-called *reduced* form, *h-bar* (ħ).[29] So here is our first formula—the Planck-Einstein relation:

$$E = h \cdot f = \hbar \cdot \omega$$

A by-product of Einstein's special relativity theory is the mass-energy equivalence relation: energy and mass are not the same, but there is an equivalence between them: they are *proportional* one to another, and the constant of proportionality is given by the $E = m \cdot c^2$ relation. It is yet another equation most of us simply *accept*, but do not really *understand*. We think we have some intuitive understanding of it: we think the $E = m \cdot c^2$ equation models a two-dimensional oscillation, but we'll come back to that later. As for now, we just want to make some substitutions. First, the *rest* mass of a photon is zero, so all of its mass comes from its motion: $m = m_v = m_c$. Its *momentum* – whatever it means[30] – is equal to $p = mv = mc$. Hence, we get:

$$E = m \cdot c^2 = p \cdot c = h \cdot f \Leftrightarrow c/f = \lambda = h/p \Leftrightarrow h = p \cdot \lambda$$

Planck's quantum of action, whose physical dimension is expressed in N·m·s, is the product of momentum (p) and wavelength (λ). It is also the product of energy (E) and cycle time ($T = 1/f$), as can be seen from re-writing the above as follows:

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

These are the two *de Broglie* relations, but we apply to them to a photon. We will soon explain what they actually mean, *physically*, so you can understand what a photon actually *is*. Before we do so, we'd like to insert one more remark on the *relativity* of things. To be precise, we'd like to make a rather philosophical remark on the supposed relativity of reference frames.

Our Universe as an absolute reference frame

The speed of a light photon and the amount of physical action it packs (Planck's quantum of action) are *not* relative: they are equal to *c* and h respectively, *always*—in contrast to the energy and the frequency, which depend on our reference frame. Am I the observer on the ground in Feynman's little story, or am I sitting in that car? The value of *c* and *h* does *not* depend on that question, but the values we'll find for E, *f*, and λ will, of course!

Let us now ask the obvious question: the frequency and the energy of our photon will depend on the reference frame but is there – by some chance – some reference for the reference frame? I tend to answer that question positively: we happen to live in *this* Universe here, where our Earth orbits the Sun, and where our Sun happens to be part of the Milky Way, which is part of the *Local Group*, which – in

going on. We will come back to this later but – in case you'd want something on this right now and right here – see my entry on *protons and neutrons* on viXra.org (http://vixra.org/abs/2001.0104).

[28] As we will see in a moment, we will also involve Planck's quantum of action in our model of an electron. That's why we inserted 'preliminary' in our answer.

[29] We'll explain the meaning of the reduced and non-reduced form of Planck's constant in a moment.

[30] We actually do know what it means. Feynman gives a brilliant interpretation of it in his *Lectures* (https://www.feynmanlectures.caltech.edu/I_34.html#Ch34-S9).

turn – is part of the Virgo Supercluster, etcetera.[31] In short, there is a *structure* here which we can use as an *anchor* for our physics. In fact, we may not only think of the Universe that we're living in as a *preferred* reference frame but as some kind of *absolute* reference frame.

That is why Feynman's digressions on (broken) symmetries and anti-matter do not make all that much sense to me. He basically argues there is no way to distinguish up and down, and left and right, from *physical experiments only*.[32] In case you don't remember the line of argument here, Feynman basically imagines we somehow manage to make contact with a 'Martian': some advanced *being* somewhere 'out there' whom we can communicate with but can't relate all those spatial binary concepts (front/back, up/down, left/right) to ours. He or she or it – whatever, let's be *male* and use 'he' – understands we're talking some *direction* in 3D space but we're just not sure he's got it right—and, likewise, he's not sure *we* got it right.

To make a long story short, mankind basically gives the mike to Feynman and – of course there is good translation – Feynman walks the Martian through all of the physics we know of. To be more specific, Feynman explains him all of his lectures on conservation laws, mirror reflections, polar and axial vectors in physics and, importantly, the weird phenomenon of CP-*a*symmetry, or the non-conservation of *parity*—don't worry: we'll come back to this in more detail. Now, our Martian friend gets all of this but – just to make sure – he wants Feynman to send him something that illustrates the concept of left and right. Unfortunately, that's the one thing we can*not* do in this imaginary experiment. As Feynman puts it:

> "We are not allowed to send him any actual samples to inspect; for instance, if we could send light, we could send him right-hand circularly polarized light and say, "That is right-hand light—just watch the way it is going." But we cannot give him anything, we can only talk to him. He is far away, or in some strange location, and he cannot see anything we can see. For instance, we cannot say, "Look at Ursa major; now see how those stars are arranged. What we mean by 'right' is …" We are only allowed to telephone him."[33]

That's the flaw of the whole argument. Because it's the final chapter in Feynman's first volume of lectures in a series that is designed to 'save the more advanced and excited student by maintaining his enthusiasm'[34], I've come to think of this thought experiment as Feynman at his worst, which, paradoxically, doesn't diminish my admiration for him as 'the Great Teacher'—not at all, actually.[35] Any case, to make a long story short, Feynman basically concludes we cannot be sure our Martian friend lives in the same Universe. It all boils down, in the end, to the difference of matter and anti-matter:

> "So if our Martian is made of antimatter and we give him instructions to make this "right" handed model like us, it will, of course, come out the other way around. What would happen when, after much conversation back and forth, we each have taught the other to make

[31] For a brief description of where we are, see the Wikipedia article on our surroundings: https://en.wikipedia.org/wiki/Milky_Way.
[32] See: *Feynman's Lectures*, Volume I, Chapter 52 (*Symmetry in Physical Laws*).
[33] For a full discussion, see my posts on time reversal and CP-asymmetry on my blog on Feynman's *Lectures* (https://readingfeynman.org/2014/05/11/time-reversal-and-cpt-symmetry-iii/).
[34] See Feynman's Preface to his *Lectures*.
[35] Feynman's biggest achievement with this *Lectures* series is that he does make you think for yourself, which he surely does in this particular lecture (I-52).

spaceships and we meet halfway in empty space? We have instructed each other on our traditions, and so forth, and the two of us come rushing out to shake hands. Well, if he puts out his left hand, watch out!"

It's a funny story and, at the same time, it's not: Feynman just keeps the 'mystery' alive here. He doesn't answer any of the obvious questions. We know those famous words of Minkowski, which he wrote in following in 1907, shortly after he had re-formulated Einstein's special relativity theory in terms of four-dimensional space-time: "*Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.*" However, it's equally true that "**the underlying geometry of Minkowskian space-time remains absolute**."[36]

The geometry of a photon

So what *is* a photon then? I've detailed that in previous papers so I will just present the basics here.[37] It is, effectively, just a point-like electromagnetic oscillation. I refer to it as the one-cycle photon model. The argument is quite basic, and so I am not sure why it's not in any basic textbook on physics: even if it's faulty, physicists should do more of an effort to come up with basic *models* of photons and/or other elementary particles, I feel. Any case, my photon model is quite simple and, hence, comments on it are very welcome because they should be equally simple—I hope, at least! Let's go through it.

Angular momentum comes in units of $\hbar$. When analyzing the electron orbitals for the simplest of atoms (the one-proton hydrogen atom), this rule amounts to saying the electron orbitals are separated by a amount of *physical action* that is equal to $h = 2\pi\cdot\hbar$. 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. The photon that is emitted or absorbed will have to pack that somehow. It will also have to pack the related energy, which is given by the Rydberg formula:

$$\mathrm{E}_{n_2} - \mathrm{E}_{n_1} = -\frac{1}{{n_2}^2}\mathrm{E}_R + \frac{1}{{n_1}^2}\mathrm{E}_R = \left(\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right)\cdot \mathrm{E}_R = \left(\frac{1}{{n_1}^2} - \frac{1}{{n_2}^2}\right)\cdot \frac{\alpha^2 \mathrm{m}c^2}{2}$$

[36] This is a philosophical comment (https://physics.nyu.edu/faculty/sokal/transgress_v2/node2.html) from an author I don't know, so I am not quite sure it means what I think it should mean. I should also repeat Feynman actually uses this 'Martian story' to illustrate symmetries and – more importantly, the corollary – asymmetries in physical laws, which we won't get into in the context of this paper. So he is *not* using it in the context of a discussion of whether or not we should take the concept of a *preferred* or *absolute* reference frame very seriously. I think we should: the concept of an *aether*, obviously, doesn't make much sense, but the concept of *our* Universe obviously does. The Wikipedia entry on aether theories offers very useful comments, including this remark from Nobel Laureate Robert B. Laughlin: "*It is ironic that Einstein's most creative work, the general theory of relativity, should boil down to conceptualizing space as a medium when his original premise [in special relativity] was that no such medium existed* [..] *The word 'aether' has extremely negative connotations in theoretical physics because of its past association with opposition to relativity. This is unfortunate because, stripped of these connotations, it rather nicely captures the way most physicists actually think about the vacuum. […] The modern concept of the vacuum of space, confirmed every day by experiment, is a relativistic aether. But we do not call it this because it is taboo.*"
[37] See: *A Classical Quantum Theory of Light* (http://vixra.org/abs/1906.0200).

To focus our thinking, let us consider the transition from the second to the first level, for which the $1/1^2 - 1/2^2$ factor is equal 0.75. Hence, the energy of the photon that is being emitted will be equal to $(0.75)\cdot E_R \approx 10.2$ eV. Now, if the total action is equal to h, then the cycle time T can be calculated as:

$$\mathrm{E}\cdot\mathrm{T} = h \Leftrightarrow \mathrm{T} = \frac{h}{\mathrm{E}} \approx \frac{4.135\times10^{-15}\mathrm{eV}\cdot\mathrm{s}}{10.2\ \mathrm{eV}} \approx 0.4\times10^{-15}\ \mathrm{s}$$

This corresponds to a wavelength of $(3\times10^{8}$ m/s$)\cdot(0.4\times10^{-15}$ s$)$ = 122 nm, which is the wavelength of the light ($\lambda = c/f = c\cdot\mathrm{T} = \mathrm{h}\cdot c/\mathrm{E}$) that we would associate with this photon energy.[38]

Let us quickly insert another calculation here. If we think of an electromagnetic oscillation – as a beam or, what we are trying to do here, as some *quantum* – then its energy is going to be proportional to (a) the square of the amplitude of the oscillation and (b) the square of the frequency. Just to make sure, we are *not* thinking of some quantum-mechanical amplitude here: we are talking the amplitude of a *physical* wave. Hence, if we write the amplitude as a and the frequency as ω, then the energy should be equal to $\mathrm{E} = \mathrm{k}\cdot a^2\cdot\omega^2$. The k is just a proportionality factor.

However, relativity theory tells us the energy will have some equivalent mass, which is given by Einstein's mass-equivalence relation: $\mathrm{E} = \mathrm{m}\cdot c^2$. Hence, the energy will also be proportional to this equivalent mass. It is, therefore, very tempting to equate k and m. We can only do this, of course, if c^2 is equal to $a^2\cdot\omega^2$ or – what amounts to the same – if $c = a\cdot\omega$. You will recognize this as a tangential velocity formula, and so you should wonder: the tangential velocity of *what*? Indeed, the a in the $c = a\cdot\omega$ formula is a radius, while the a in the $\mathrm{E} = \mathrm{k}\cdot a^2\cdot\omega^2$ formula that we started off with is an amplitude: so why would we suddenly think of it as a radius now? I can*not* give you a very convincing answer to that question but – intuitively – we will probably want to think of our photon as having a circular polarization. Why? Because it is a boson and it, therefore, has angular momentum. To be precise, its angular momentum is $+\hbar$ or $-\hbar$. There is no zero-spin state.[39] Hence, if we think of this classically, then we will associate it with circular polarization.

We are now ready for some calculations. If the energy E in the Planck-Einstein relation ($\mathrm{E} = \hbar\cdot\omega$) and the energy E in the energy equation for an oscillator ($\mathrm{E} = \mathrm{m}\cdot a^2\cdot\omega^2$) are the same[40] – and they should be because we are talking about something that has some energy – then we get the following formula for the amplitude or radius a:

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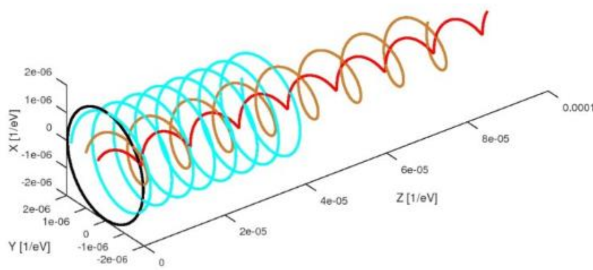
[38] Just so you can imagine what we are talking about, this is short-wave ultraviolet light (UV-C). It is the light that is used to purify water, food or even air. It kills or inactivate microorganisms by destroying nucleic acids and disrupting their DNA. It is, therefore, harmful. The ozone layer of our atmosphere blocks most of it.

[39] This is one of the things in mainstream quantum mechanics that bothers me. All courses in quantum mechanics spend like two or three chapters on why bosons and fermions are different (spin-one versus spin-1/2) and, when it comes to the specifics, then the only boson we actually know (the photon) turns out to *not* be a typical boson because it can*not* have zero spin. Feynman gives some haywire explanation for this in section 4 of *Lecture* III-17. I will let you look it up (Feynman's *Lectures* are online) but, as far as I am concerned, I think it's really one of those things which makes me think of Prof. Dr. Ralston's criticism of his own 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*." (John P. Ralston, *How To Understand Quantum Mechanics*, 2017, p. 1-10)

[40] In case the reader would wonder where the ½ factor went, we should mention this is the formula for an oscillation in *two* dimensions. Again, we are talking two *physical* dimensions. For more details on the oscillator model, see our paper on the *Zitterbewegung* electron (http://vixra.org/abs/1905.0521).

$$\mathrm{E} = \hbar \cdot \omega = \mathrm{m} \cdot a^2 \cdot \omega^2 \Leftrightarrow \hbar = \mathrm{m} \cdot a^2 \cdot \omega \Leftrightarrow a = \sqrt{\frac{\hbar}{\mathrm{m} \cdot \omega}} = \sqrt{\frac{\hbar}{\frac{\mathrm{E}}{c^2} \cdot \frac{\mathrm{E}}{\hbar}}} = \sqrt{\frac{\hbar^2}{\mathrm{m}^2 \cdot c^2}} = \frac{\hbar}{\mathrm{m} \cdot c}$$

This is the formula for the Compton radius of an electron ! How can we explain this? What relation could there possibly be between our *Zitterbewegung* model of an electron[41] and the quantum of light? We do not want to confuse the reader too much but things become somewhat more obvious when staring sufficiently long at the illustration below (Figure 1).



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

Figure 1: The Compton radius must decrease with increasing velocity

We think of the *Zitterbewegung* of a free electron as a circular oscillation of a pointlike *charge* (with *zero* rest mass) moving about some center at the speed of light. However, as the electron starts moving along some *linear* trajectory at a relativistic velocity (i.e. a velocity that is a *substantial* fraction of *c*), then the *radius* of the oscillation will have to diminish – because the tangential velocity remains what it is: *c*. The geometry of the situation shows the circumference – so that's the Compton *wavelength* $\lambda_C = 2\pi \cdot a = 2\pi\hbar/\mathrm{m}c$ – becomes a wavelength in this process.

Of course, we should remind ourselves that the m in the $a = \hbar/\mathrm{m}c$ equation here is *not* the mass of the electron but the (equivalent) mass of the photon. The Compton radius of a photon is, therefore, different than the Compton radius of an electron. Let us quickly calculate it for our 10.2 eV photon. We should, of course, express the energy in SI units (10.2 eV ≈ 1.634×10^{-18} *J*) to get what we should get:

$$a = \frac{\hbar}{\mathrm{m} \cdot c} = \frac{\hbar}{\mathrm{E}/c} = \frac{(1.0545718 \times 10^{-18}\, J \cdot s) \cdot (3 \times 10^8\, m/s)}{1.634 \times 10^{-18}\, J} \approx 19.4 \times 10^{-9}\ \mathrm{m}$$

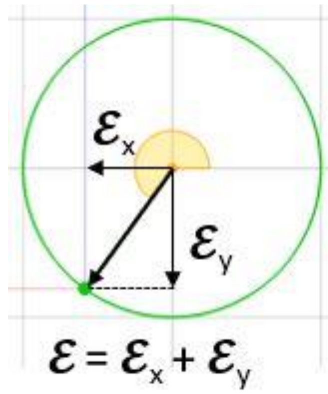
How does this compare to the Compton radius of an electron? The Compton radius of an electron is equal to about 386×10^{-15} m, so that's about 50,000 times *smaller* than the Compton radius of a photon. Unsurprisingly, that's the ratio between the electron's (rest) energy (about 8.187×10^{-14} *J*) and the photon energy (about 1.634×10^{-18} *J*). It is somewhat counterintuitive that the Compton radius is *inversely* proportional to the (rest) mass or energy, but that's how it is.[42]

[41] See the reference above.

[42] While counterintuitive, the calculation is consistent. The reader can verify this by calculating the Compton radius for highly energetic photons. For example, the X-ray photons in the original Compton scattering experiment had an energy of about 17 keV = 17,000 eV and modern-day experiments will use gamma rays with even higher energies. One experiment, for example, uses a cesium-137 source emitting photons with an energy that is equal to 0.662

Let us now answer the most obvious question: what *is* that amplitude? It's a (rotating) field. We will use the elementary wavefunction to represent the rotating *electromagnetic* field vector (see Figure 2). Remembering the $\boldsymbol{F} = q_e\boldsymbol{\mathcal{E}}$ equation – with q_e as the unit charge – you should think of it as *force* acting on an elementary charge if there would be one, which – let us remind you – is *not* the case: we think photons do not carry any charge.[43]

Figure 2: The one-cycle photon



This 'one-cycle photon model' is delightfully simple: the photon is just one single cycle 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 $E = mc^2$ 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 can also calculate the strength of the electromagnetic field. How can we do that? We can do it using the relation between energy and force. Indeed, energy is some force over a distance and, hence, the force must equal the ratio of the energy and the distance. What distance should we use? The force will vary over the cycle and, hence, this distance is a distance that we must be able to relate to this

MeV = 662,000 eV. One can see these high photon energies bridge the gap with the rest energy of the electron they are targeting.

[43] Many other writers do think a photon, somehow, carries charge—if only to explain pair production. We have no precise explanation for electron-positron pair production but the idea photons carry charge does not appeal to us. See, for example, our paper on the nature of protons and neutrons (http://vixra.org/abs/2001.0104).

fundamental cycle. Is it the Compton *radius* (a) or the wavelength (λ)? They differ by a factor 2π only, so let us just try the radius and see if we get some kind of sensible result:

$$\mathrm{F} = \frac{\mathrm{E}}{a} = \frac{2\pi \cdot \mathrm{E}}{\lambda} = \frac{2\pi \cdot h \cdot f}{\lambda} = \frac{2\pi \cdot h \cdot c}{\lambda^2}$$

Does this look weird? Not really. We get the E·λ = h·c equation from *de Broglie*'s h = p·λ = m·c·λ = E·λ/c equation and the equation above is fully consistent with it:

$$\frac{\mathrm{E}}{a} = \frac{2\pi \cdot h \cdot c}{\lambda^2} \Leftrightarrow \mathrm{E} \cdot \lambda = \frac{2\pi \cdot a \cdot h \cdot c}{\lambda} = h \cdot c$$

But – *Hey!* – the force on what? Good question. Now that we have the force, we can calculate the electromagnetic field – which we denote by ***ℰ***[44] – is the force per unit charge which, we should remind the reader, is the *coulomb* – *not* the electron charge. Why? Because we use SI units. We, therefore, get a delightfully simple formula for the strength of the electromagnetic field vector for a photon:

$$\mathcal{E} = \frac{\frac{2\pi hc}{\lambda^2}}{1} = \frac{2\pi hc}{\lambda^2} = \frac{2\pi \mathrm{E}}{\lambda} = \frac{\mathrm{E}}{a}$$

The force and the electromagnetic field vectors are the same thing here and, hence, their magnitude is one and the same thing as well: it is just the ratio of the energy and the Compton radius. Does this make sense? What about units? When calculating the field, we divided by 1 *coulomb* and the physical dimension is, therefore, equal to [ℰ] = [E/a] *per coulomb*. A *joule* is a newton·meter and [E/a] is, therefore, equal to N·m/m = N. We're fine. It's just two different perspectives on one and the same thing. It shows the reference frame doesn't matter: the ***F*/*ℰ* =** q *ratio* is just the same. The electric charge appears as a simple – but *absolute* – *scaling constant* – here.

Let us calculate its value for our 10.2 eV photon (using SI units once again, of course):

$$\mathcal{E} \approx \frac{1.634 \times 10^{-18}\, J}{19.4 \times 10^{-9}\, m \cdot C} \approx 84 \times 10^{-12} \frac{\mathrm{N}}{\mathrm{C}}$$

What do we mean with a *scaling constant*? Same thing as the amplitude a, which appears as a natural distance unit here: if we use it as a divisor for the energy, then we get the field strength. You may not immediately get this but, as far as I am concerned, I'd think **this is a *very* nice result.**[45]

Needless to say, all of these laws respect relativity theory: the measured values of the energy, the wavelength and, hence, of the field strength will depend on your reference frame. However, the underlying *geometry* of the photon – the quantum of light – looks pretty absolute. 😊

Jean Louis Van Belle, 19 January 2020

[44] The *ℰ*, *E* and E symbols should not be confused! Needless to say, boldface (***ℰ***) denotes the *vector*. The non-bold *ℰ* is just its magnitude. We write: $|\boldsymbol{\mathcal{E}}| = \mathcal{E}$.
[45] I realize this sounds somewhat abstruse. Hence, I will try to be somewhat more explicit in the next version of this article.