The metaphysics of physics: the concepts of force, charge, and mass

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Summary: This paper complements earlier papers on the metaphysics of physics by offering some thoughts and reflections on the most fundamental physical concepts: the idea of force, energy and mass.

Contents

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The idea of a force

Newton's force law tells us a force changes the state of motion of an object, and Maxwell's equations tell us a force does so by acting on a *charge*. The force we know best is the electromagnetic force: it acts on an electric charge.

The corollary of the idea of a force being that what changes the state of motion of an object is that the state of motion of an object does *not* change in the absence of a force: such resistance to change is referred to as *inertia* and is captured by the concept of mass. If the nature of a force is defined by the charge it acts upon, then we should probably also define the concept of mass in terms of the force or the charge it acts upon. The concept of *electromagnetic* mass may, therefore, be quite useful, and we will, therefore, come back to it later.

Let us first think about other forces, charges and masses that may or may not exist. There is the gravitational force, of course—but Einstein did not think of it as a force, and so we will not dwell on it either here.

We may also think of some kind of strong force. Indeed, because protons stay together in multi-proton nuclei, physicists also believe some kind of short-range strong force must exist: this strong force must act on some strong charge whose nature is not well understood. The idea here is rather simple: because protons carry positive charge, the electrostatic repulsive force between them should push them apart. Hence, some other – stronger – force must keep them together. This inspired Hideki Yukawa to propose a potential function for a *nuclear* force—some new force that, supposedly, holds nucleons together: protons as well as neutrons. The Yukawa potential has the following shape:

$$\mathrm{U}(r) = -\frac{\mathrm{g}_{\mathrm{N}}^2}{4\pi}\frac{e^{-r/a}}{r}$$

This formula reflects the formula for the electrostatic potential:

$$\mathrm{V}(r) = \frac{\mathrm{q}_{\mathrm{e}}^2}{4\pi\varepsilon_0}\frac{1}{r} = \mathrm{e}^2\frac{1}{r}$$

Yukawa's formula differs from Coulomb's formula because of the minus sign (but that is because the electrostatic and strong forces are opposite) and, most importantly, because of the $e^{-r/a}$ factor, which is there to ensure that, at distances smaller than the *range* parameter a, the strong *attractive* force would, effectively, be stronger than the electrostatic *repulsive* force.

Yukawa's formula also misses the equivalent of the electric constant (ε_0). This is an oft-missed point and we do not think of it as a minor detail. In fact, we think it is a grave mistake: if there is something like a strong force, then there must something like a strong charge and, hence, Yukawa should have inserted some kind of nuclear constant. Because Yukawa had the freedom to choose a *unit* for this new hypothetical strong charge, its numerical value could be one, but it would still have some *physical* dimension to ensure dimensional consistency on both sides of his U(*r*) equation. The discussion warrants a small digression to highlight the point.

Electric charge is measured in units of *coulomb*, and it is a fundamental unit: the electron charge is the electron charge—regardless of the reference frame. As such, it is as fundamental as *c* or *h*.[1] If the strong force would be as fundamental as the electromagnetic force, then the charge it acts upon should be as fundamental as the electric charge. In one of our previous papers, we invented a temporary unit for it: the *dirac*, which we abbreviated as Y to not only honor Dirac but Yukawa as well.[2] Hence, if ε_0 is expressed in $C^2/N{\cdot}m^2$, then our nuclear constant (which we will denote as υ_0) will be expressed in $Y^2/N{\cdot}m^2$. It is, then, easy to calculate the value of the nucleon charge as[3]:

$$g_N = \sqrt{e \cdot \alpha \cdot h \cdot c \cdot \upsilon_0} = 6.27723\ldots \times 10^{-14}\ \mathrm{Y}$$

It is a weird but interesting formula even if its key purpose in the context of this paper is to demonstrate a philosophical point only. It consists of a mathematical constant (Euler's number) which is there because of the exponential function in Yukawa's formula[4], three natural constants (α, *h* and *c*)[5] and a *physical* proportionality constant whose only function is to ensure dimensional consistency and whose *numerical* value is, therefore, unity.

As mentioned, the formula currently only serves to demonstrate a philosophical point: the formulas does not *prove* such strong force effectively exists. Other reasons may explain why nucleons tend to stick together inside of the nucleus. Indeed, considering electrostatic repulsion alone, as Yukawa and other theorists usually do, narrows the perspective considerably. If we think of the *electric* charges inside of the nucleus as, somehow, moving around, the *magnetic* forces between them might act as counterbalancing the electrostatic repulsive force. You should think of the *attraction* between two wires carrying current in the same direction or – more relevant in this context – between two *loops* of current acting as magnetic dipoles.[6]

In fact, we are very much intrigued by calculations in the context of the forces between charged particles in accelerator beams here. One author – in the context of a very interesting article on relativity

[1] The 2019 revision of SI units defines the coulomb in terms of the elementary charge. To be precise, the coulomb is the charge of $1/1.602176634{\times}10^{-19}$ protons, *exactly*.

[2] The choice of Y is also consistent with our choice of an *upsilon* symbol (υ) for the nuclear constant.

[3] See, for example, my paper with some thoughts on the nature of protons and neutrons (http://vixra.org/abs/2001.0104).

[4] It would be tempting to try other functional forms but these would result in very complicated calculations and, in any case, in the lack of other good reasons, Yukawa's choice of the natural exponential function is, *a priori*, as good or as bad as any other choice he could have made.

[5] While the fine-structure constant has no physical dimension (it is a scalar), it is obviously a *physical* – rather than mathematical – constant. The fine-structure constant has many meanings, but we primarily think of it as a scaling constant in a layered model of electron motion (http://vixra.org/abs/1812.0273).

[6] For a non-technical discussion of the idea, see the *Encyclopædia Britannica* article on it: https://www.britannica.com/science/magnetism/Repulsion-or-attraction-between-two-magnetic-dipoles. We like this article because it effectively also discusses *nuclear* magnetic moment. It does so in the context of technology (magnetic resonance imaging) but it serves to illustrate the point we're trying to make here.

– actually claims that the charges on the surface of the beam and inside the beam would experience zero radial force *if the charged particles would move at the speed of light*.[7]

Finally, one may also want to wonder why electron orbitals consist of electron *pairs* or – why in the context of superconduction – Cooper pairs of like charges emerge. In short, considering electrostatic forces alone and then argue some strong force must counter these is, obviously, a bit of a flawed argument.

The stronger force hypothesis

Having said this, we actually do believe some kind of strong force inside of the nucleus exists. However, the reason has got nothing to do with the idea some other force should counter the electromagnetic forces inside of a nucleus. The most compelling reason to believe some enormous force must govern the nucleus is the extraordinarily *large mass* and the equally extraordinary *small size* of protons and neutrons as compared to electrons. The energy *density* inside of protons and neutrons is, effectively, *massive* as compared to electrons.

We have elaborated the *Zitterbewegung* model of an electron elsewhere and, hence, will not repeat ourselves here.[8] We just note it does what it is designed to do: it yields an elegant explanation of both the mass and the *Compton* radius of an electron in terms of a local oscillation of a pointlike electric charge.[9] By now, the skeptical reader may be inclined to stop reading all of this, so we will try to revive his or her interest by noting the *Zitterbewegung* hypothesis goes back to Erwin Schrödinger. Schrödinger stumbled upon the idea while exploring solutions to Dirac's wave equation for free electrons, and it's probably worth quoting Dirac's summary of it once more:

> "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)

David Hestenes revived the *Zitterbewegung* (often abbreviated as *zbw*) interpretation in the 1970s and 1980s, basically turning it into the ring electron model, which thinks of the electron as a unitary charge orbiting *at the speed of light* around some center, thereby generating a strong magnetic field which keeps the current going. As such, it is a rather nice example of a *perpetuum mobile* or a self-sustaining

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[7] See: 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).

[8] For a brief overview, see our (critical) discussion of Oliver Consa's classical calculations of the anomalous magnetic moment (http://vixra.org/abs/2001.0264). We also have more comprehensive papers on the topic (see, for example, http://vixra.org/abs/1905.0521).

[9] The oscillation is usually thought of as a ring current, and the pointlike charge may be associated as having some small but non-zero radius itself, which is supposed to explain Thomson scattering, as opposed to Compton scattering (see below).

oscillation. More importantly, the model does allow us to explain the two different radii we get from elastic versus inelastic scattering experiments (Thomson versus Compton scattering).[10]

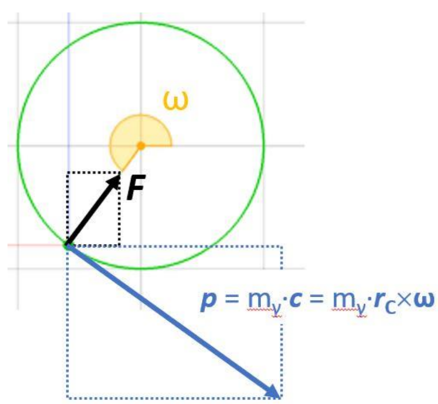
The point is: the electric current and the associated electromagnetic force allow us to *calculate* the Compton radius of an electron (r_C), and its formula effectively corresponds to what is *measured* in those scattering experiments:

$$r_{\mathrm{C}} = \frac{\hbar}{\mathrm{m_e} c} = \frac{\hbar c}{\mathrm{E}} = 0.386 \ldots \times 10^{-12}\, m$$

We used Einstein's mass-energy equivalence formula above: $E = m_e \cdot c^2$. It is, effectively, very important to underline that, in our particular model of the *zbw* electron, *all of the electron mass is explained as the equivalent mass of the energy in the (two-dimensional) oscillation of the pointlike charge*. The pointlike charge itself has zero rest mass: all of its mass is derived from its motion. As such, it reminds us of a photon which, supposedly, also has zero rest mass but which can be associated with some *effective* mass as well, which it derives from its motion.[11]

The formula for the Compton radius establishes an inverse proportionality between the radius (or size) of our particle (the electron, in this case) and its energy. Now, we said all of the energy of the electron is electromagnetic: the *mass* of the electron – as measured in experiments (about 0.511 MeV/c^2) – is the equivalent mass of the energy in the oscillation. The oscillation is electromagnetic and we can, therefore, calculate the energy from the electromagnetic force that drives the pointlike charge. The basic assumptions are depicted in Figure 1.

Figure 1: The ring current model of an electron



[10] Thomson scattering is referred to as *elastic* scattering because the energy of the photons remains unchanged. In contrast, Compton scattering involves some interaction between the photon and the electron. We think of the photon as being briefly absorbed, before the electron emits another photon of *lower* energy, and the energy difference between the incoming and outgoing photon gets added to the *kinetic* energy of the electron.

[11] Some authors refer to the pointlike charge as a toroidal or electron photon but we find this term misplaced because we think one should not associate a photon with electric charge, and vice versa. In fact, we think this distinguishes photons from matter: photons do not carry charge. Matter does—even neutrons, as evidenced by the fact they have a magnetic moment. As for the mysterious neutrinos, we may say a few words about them later.

We distinguish between the *effective* mass of the pointlike charge, which we denote as m_γ[12], and the mass of the electron as a whole, which we denote as m_e. Based on the geometry of the situation, it is easy to show that $m_\gamma = m_e/2$. One can also show that the ratio between the force *F* and the momentum *p* must be equal to the ration between the speed of light and the radius $a = r_C$, so we can write: $F/p = c/a$. To make a long story short, we can relate the force and the energy as follows:

$$F = \frac{p \cdot c}{a} = \frac{\mathrm{m}_\gamma \cdot c^2}{a} = \frac{\mathrm{m_e} \cdot c^2}{2a} = \frac{\mathrm{E}}{2a} \Leftrightarrow a = \frac{\mathrm{E}}{2F}$$

This shows the radius is *inversely* proportional to the strength of the force. In other words, if we'd find ourselves in some other universe, where the electromagnetic force would – for some totally random reason – be much *stronger*, the electrons there would be smaller than our electrons here.

Of course, you'll immediately note the obvious mistake in this argument: if the force would be stronger, the energy would be much larger as well, wouldn't it? That is correct. Let us, therefore, try to develop a more general argument. Let us *not* make any assumption about the strength of the force. However, we will assume its *structure* is the one we presented above: a circular current of the *charge* it acts on will produce a field which keeps that charge in the orbit which it happens to be in. We can now *derive* the radius of the oscillation in another way. For some reason we do not understand, the angular frequency of the motion respects the Planck-Einstein relation:

$$a = \frac{\hbar}{\mathrm{m}c} = \frac{\hbar}{\mathrm{E}/c} \Leftrightarrow \mathrm{E} = \frac{\hbar c}{a} = \hbar\omega = \mathrm{h}f = \mathrm{h/T}$$

These calculations are *not* mere entertainment. We get fantastic but not necessarily impossible values for the cycle time and the current here[13]:

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

$$\mathrm{I} = \mathrm{q_e}f = \mathrm{q_e}\frac{\mathrm{E}}{h} \approx (1.6 \times 10^{-19}\ \mathrm{C})\frac{8.187 \times 10^{-14}\ \mathrm{J}}{6.626 \times 10^{-34}\ \mathrm{Js}} \approx 19.8\ \mathrm{A}$$

The point is: one obtains the Compton radius most easily from combining the $\mathrm{E} = \hbar \cdot \omega$, $c = a \cdot \omega$ and $\mathrm{E} = \mathrm{m} \cdot c^2$ relations, as shown below.

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[12] The *gamma* (γ) in the subscript refers to the Lorentz factor. However, one should not think of the charge as a photon. Photons do not carry charge. For our photon model, see our other papers (e.g. http://vixra.org/abs/2001.0345). At the same time, we do not mind the association with a photon because, as we noted above, the pointlike charge is photon-like in the sense that it (also) travels at the speed of light. Alexander Burinskii, a Russian physicist who specializes in physical electron models, wrote me the following when I first contacted him (December 2018): "I know many people who considered the electron as a toroidal photon and do it up to now. I also started from this model about 1969 and published an article in JETP in 1974 on it: "Microgeons with spin". Editor E. Lifschitz prohibited me then to write there about Zitterbewegung [because of ideological reasons], but there is a remnant on this notion. There was also this key problem: what keeps [the pointlike charge] in its circular orbit?" We think we managed to answer his question.

[13] These values are also obtained by other authors, even if some of the other calculations differ. See our above-mentioned *critique* of Consa's calculations.

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

Let us now apply the E = ħ·ω, $c = a \cdot \omega$ and E = m·c^2 relations to the mass/energy of proton (or a neutron[14]), we get this:

$$a_\mathrm{p} = \frac{\hbar}{\mathrm{m_p} \cdot c} = \frac{\hbar}{\mathrm{E_p}/c} = \frac{(6.582 \times 10^{-16}\ \mathrm{eV} \cdot s) \cdot (3 \times 10^8\ m/s)}{938 \times 10^6\ \mathrm{eV}} \approx 0.21 \times 10^{-15}\ \mathrm{m}$$

The result that we obtain here is about 1/4 of the experimentally measured value. Indeed, the radius of a proton is thought to be around 0.83 or 0.84 fm.[15] Hence, the *order of magnitude* is right, at least! Have we discovered the strong force? Is it just a stronger *variant* of the electromagnetic force?

Probably not. Again, this calculation only serves to demonstrate a philosophical point: if the energy (and equivalent mass) of nucleons is the energy of some oscillating *strong* charge, then the energy density of protons and neutrons suggest it is going to be a very strong force, indeed!

To illustrate the point, the above F = E/2a formula yields a force of 0.115 N for the electron: such force gives a mass of about 115 *gram* (1 g = 10^{-3} kg) an acceleration of 1 m/s per second, which is humongous on the *pico*meter scale that we are talking about here. However, terms such as massive or humongous suddenly become very relative when using the same formulas to calculate the value of the presumed strong(er) version of the oscillatory force inside a proton. We will let you go through them and, to keep the exercise somewhat interesting, you may to think of they'd imply in terms of spacetime curvature.

What about the weak force?

To conclude this rather philosophical introduction, we should probably say a few words about the weak force. The weak force is supposed to explain why things fall apart, or why particles are *unstable*, rather than stable. We prefer to *not* think of decay or disintegration as a force. It is, in fact, the exact *opposite* of the idea of a force: a force is supposed to keep things together.

In the same vein, we like to add we do not want to entertain the idea of messenger particles or force carriers – virtual photons, gluons, or whatever other bosons or metaphysical constructs that have been invented since Yukawa first presented these ideas. Indeed, it is unfortunate that – instead of realizing he

[14] The mass of a neutron is about 939,565,413 eV/c^2 and about 938,272,081 eV/c^2 for the proton. Hence, the energy *difference* is a bit less than 1.3 MeV. It is, therefore, very tempting to think a neutron might, somehow, combine a proton and an electron: the electron mass is about 0.511 MeV/c^2 and, hence, we may think of the remaining difference as some kind of binding energy—the attractive force between the positive and a negative charge, perhaps? These thoughts are, obviously, very speculative. We did explore some of these, however, in our paper on the nature of protons and neutrons (http://vixra.org/abs/2001.0104), and we very much welcome comments.

[15] We refer to Wikipedia for a very readable account of the experiments and their results (https://en.wikipedia.org/wiki/Proton_radius_puzzle). Earlier measurements were somewhat inconclusive because they yielded a radius between 0.84 and 0.90. However, recent research suggests the so-called proton radius puzzle has been solved (see: https://physicstoday.scitation.org/do/10.1063/PT.6.1.20191106a/full/). For those who would wonder, we may, perhaps, also note the same calculations do work very well for the muon-electron. We've done these calculations in another speculative paper (http://vixra.org/abs/1908.0430).

was actually proposing the existence of a new *charge* – he used his formula to derive a hypothetical *nuclear force quantum*.[16]

It is now time to turn to the concept of mass—or to the concept*s* (*plural*) of mass, we should say.

Kinetic, electromagnetic and other masses

We should probably not remind the reader of the *classical* concept of electromagnetic mass. If so, we will refer him or her to an equally classic textbook, such as Feynman's Lectures.[17] These classical calculations are usually based on the assembly of a spherical shell or sphere of charge. Another, more intricate, argument involves the concept of *field momentum*.[18] However, they all involve the idea of *naked* charge, i.e. electric charge stripped of *any other attribute or idea*. Hence, the basic idea, here too, is that charge is just charge, *with zero rest mass*. As such, these models are not entirely dissociated from our modern-day *zbw* model of an electron.[19]

We should highlight the key differences and issues, however. First, these classical calculations do usually *not* use Compton radius, but the (classical) Thomson radius, which we can write as[20]:

$$r_{\mathrm{e}} = \alpha \cdot r_{\mathrm{C}} = \frac{\mathrm{q_e^2}}{4\pi\varepsilon_0 \hbar c}\frac{\hbar}{\mathrm{m_e}c} = \frac{\mathrm{e}^2}{\mathrm{m_e}c^2} = \frac{\mathrm{e}^2}{\mathrm{E_e}}$$

For example, if we assume all of the electron charge is to be assembled in a spherical shell with radius a = r_{e}, then the energy needed to do so, will be equal to[21]:

$$\mathrm{U} = \frac{1}{2}\frac{\mathrm{e}^2}{a} = \frac{1}{2}\frac{\mathrm{e}^2\mathrm{E}}{\mathrm{e}^2} = \frac{1}{2}\mathrm{E}$$

If the *form factor* is a proper sphere instead of a *shell*, then we get:

$$\mathrm{U} = \frac{3}{5}\frac{\mathrm{e}^2}{a} = \frac{3}{5}\mathrm{E}$$

[16] For a brief but accessible treatment of this matter, see Aitchison and Hey's introduction to their *Gauge Theories in Particle Physics* (2013). I am quoting this textbook rather than any other because it also incorporates the Higgs mechanism: the 'missing' scalar field that is supposed to explain mass and is now thought of as being real. Why? Because some CERN data might be interpreted as some 'signature' of it and, more importantly, because the current Nobel Prize Committee thinks such 'signals' or 'signatures' give the hypothesis sufficient credibility.

[17] See: Feynman's Lectures, Volume II, Chapter 28, on *Electromagnetic mass.*

[18] See section 2 in Feynman's above-mentioned *Lecture* (the field momentum of a moving charge).

[19] Note that calculations of electromagnetic mass never revolve around protons because their mass is inexplicably large as compared to that of an electron, as we pointed out already.

[20] The formula uses the fine-structure constant $\alpha = \mathrm{q_e}^2/4\pi\varepsilon_0\hbar c = \mathrm{e}^2/\hbar c \approx 0.0073$, which relates all of the three radii of the electron (Thomson, Compton and Bohr radius). The fine-structure constant has several meanings but, as mentioned before, we primarily think of it as a scaling constant in a layered model of electron motion. It is surely *not* some "magical" or "God-given number." Its meaning is perfectly comprehensible. See our paper on the meaning of the fine-structure constant (http://vixra.org/abs/1812.0273).

[21] For the formulas of the energy, we refer to Feynman's *Lecture* on electromagnetic mass (Volume II, Chapter 28). Needless to say, with E we mean the actual *total* energy of the electron, i.e. about 0.511 MeV/c^2).

The more advanced idea of using the idea of field momentum – an argument which takes some time to explain and, hence, which we won't elaborate here – gives us a value of 0.75 (3/4) times the actual electron energy:

$$\mathrm{U} = \frac{3}{4}\frac{\mathrm{e}^2}{a} = \frac{3}{4}\mathrm{E}$$

Are we getting there? Can we *assemble* an electron, somehow, so as to make sure the energy of the assembly adds up to the total electron mass? No. Feynman writes the following about that:

> "It is impossible to get all the mass to be electromagnetic in the way we hoped. It is not a legal theory if we have nothing but electrodynamics. Something else has to be added. Whatever you call them—"rubber bands," or "Poincaré stresses," or something else—there have to be other forces in nature to make a consistent theory of this kind. Clearly, as soon as we have to put forces on the inside of the electron, the beauty of the whole idea begins to disappear. Things get very complicated. You would want to ask: How strong are the stresses? How does the electron shake? Does it oscillate? What are all its internal properties? And so on. It might be possible that an electron does have some complicated internal properties. If we made a theory of the electron along these lines, it would predict odd properties, like modes of oscillation, which haven't apparently been observed. We say "apparently" because we observe a lot of things in nature that still do not make sense. We may someday find out that one of the things we don't understand today (for example, the muon) can, in fact, be explained as an oscillation of the Poincaré stresses. It doesn't seem likely, but no one can say for sure. There are so many things about fundamental particles that we still don't understand. Anyway, the complex structure implied by this theory is undesirable, and the attempt to explain all mass in terms of electromagnetism—at least in the way we have described—has led to a blind alley."[22]

What rubbish! Doing some more thinking about the equivalent mass of *magnetic* forces resulting from the *motion* of charge would have solved the problem!

Richard Feynman was a clever man, and the ring electron model had been around for quite a while already. Consa offers a short but interesting history of the idea, and it goes all the way back to 1915.[23] Also, Einstein clearly distinguished between the "longitudinal" and "transverse" mass of a moving charge.[24]

Why are/were gems like this hidden from common sight for so long?

The directional aspect of energy (and, therefore, of mass) is somehow we will want to explore in a second version of this paper. As for now, we will sign off and let the matter rest—literally!

Jean Louis Van Belle, 21 January 2020

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[22] Feynman's *Lectures*, section II-28-4 (https://www.feynmanlectures.caltech.edu/II_28.html).
[23] Consa's paper can be found on: http://www.ptep-online.com/2018/PP-53-06.PDF. We should mention David Hestenes also refers to earlier calculations by Antonio F. Rañada. We found the link (https://link.springer.com/article/10.1007/BF00401864) but have not examined this paper in detail.
[24] See p. 21 of the English translation of Einstein's article on special relativity, which can be downloaded from: http://hermes.ffn.ub.es/luisnavarro/nuevo_maletin/Einstein_1905_relativity.pdf.