Why the free Electron mass plus free Proton mass Exceeds the Bohr Hydrogen mass

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The National Institute of Standards and Technology (NIST) gives the mass of the simple Bohr Hydrogen atom (H-1) as less than the sum of NIST values for a free electron rest mass plus a free proton rest mass. NIST is likely correct, but that contradicts a few writings by this author and some other scientists too. When a distant electron travels very fast toward its orbit around a proton, one might think that causes a "relativistic" mass increase. While there are externally forced ways to increase mass with increased velocity, yet for isolated systems, their internal potential energies may act to increase the velocity of their parts without the systems mass increasing. We discuss that and a few of the many related and profound issues in this paper.

Keywords: Bohr, hydrogen, velocity, mass, decrease

1. Introduction

Despite statements in some of author's previous papers about the Bohr atom having more mass than the greatly separated electron and proton rest mass, the 'NIST" data now indicates the opposite. And the author now tries to explain why NIST is likely right. The issue has profound implications and raises many additional questions, but only a few can and will be addressed in this limited space paper. (Hereafter, this author will often refer to himself as I, me, or he.)

Important: Almost all physics oriented scientists realize and accept that there are very powerful cyclotrons and other accelerators that accelerate basic particles to nearly the velocity of light. And thus the particle mass can be greatly increased! For example, using rather recent scientific advances, the proton may be accelerated enough to incur a mass increase of about 100 times its rest mass. Yet, when a simple "free" electron is naturally attracted toward a proton, moves closer to it and commences to orbits it speedily, that orbiting electron has lost mass! (The proton, although mutually orbiting much more slowly, has likely lost some mass too.) Even if one adds the emitted photon mass to the mass of the Hydrogen-1 atom – that total mass might equal, but still will not exceed – the total mass of the greatly separated proton plus electron mass before the atom was formed.

So the above seems somewhat paradoxical – a mass gain for one moving particle, and a mass loss for the same particle under seemingly not very different circumstances?

I find this and many related issues difficult to explain in all their details, but I think this paper makes some progress toward that goal. But readers are encouraged to note any possible pitfalls, because, for example, I may sometimes draw nearly obvious inferences, but not fully justified, or even harbor misunderstandings about experiments and evidence.

The subject of the mass of the free electron plus free proton vs. the mass of the Bohr atom – has been rather well introduced by at least one "chat-group" [1]. Most got their conclusions right by arguing roughly as follows: ""It takes the input of 13.6 eV of energy, or work, to push the electron of the Bohr atom to a most outer orbit or slightly further. That is also known as the "ionization energy" for the hydrogen atom. Thus, the energy of the Bohr atom in its ground state is less than the sum of the free proton and free electron energies. Thus, it follows, presumably, that the sum of masses of the latter exceeds the ground state mass of the Hydrogen atom, by the mass equivalent of that much ionization energy, also!""

And for a second Bohr atom in its ground state, the reverse could occur. After, say, the electron of the first atom jumped to its inner-most orbit and emitted a photon – that photon could fly to the far away second Bohr atom which would absorb that photon energy and mass. And that would cause the ejection of its inner-most orbital electron to a far away ("ionized") location. And then the mass of the free electron plus proton rest masses would exceed the mass of the Bohr atom, which previously hosted the orbital system.

((Introductory college physics textbooks generally have the potential energy of attraction imparting kinetic energy to the electron so it will obit the proton. And also so that it makes a photon and send it fast away from the scene. But, alternatively, maybe we should imagine that that potential energy has merely, in a catalytic way, interacted with, triggered, and converted the already existing rest masses and their mc^2 energies in such a way as to

achieve the final outcomes! (The so-called "lost potential" energy may still exist, but is hidden inside or outside the particle systems).))

Einstein published two papers on Special Relativity Theory in 1905, the first, on June 30, which was rather long, which we will call his "6-30-1905 paper" [2]. But on Sept. 27, 1905, Einstein published his second paper, this time very short and on "$E/c^2 = m$ ", which we will call his "9-27-1905 paper"[3].

The first paper seems to discuss the mass vs. velocity relations for an electron travelling parallel vs. normal to a potential field, and I found it confusing, misleading, irrelevant or wrong when I tried to apply it to the Bohr model and action. (A few years after 1905, others adapted certain aspects of its equations to describe velocity vs. mass changes for other masses such as protons, neutral particles and bodies in the way we recognize today. And as occurs in many important kinds of physical behaviors.)

But the later paper by Einstein, his 9-27-1905 paper, seemed more relevant and helpful, regarding the Bohr atom and its actions. In effect, it simply stated that if radiation energy, i.e., a photon with energy "E", is emitted by a body, then the mass of the emitting body is decreased by the mass of that radiation, (the mass of photon emitted). And the mass,"m", of the radiation emitted (the photon) is equal to the Energy "E" of that photon, divided by c^2, the speed of light squared: I.e., $(E/c^2) = m$.

Let us now apply that by supposing that an initial proton and a far away electron constitute a system. Then, regardless of subsequent events and motions purely internal to that system, let us suppose that system emits radiation, a photon with energy "E". (And that "E" is received, measured and verified by a very special photo detector external to the system.) Since that photon was traveling at speed "c", the 9-27-1905 paper of Einstein says that the emitting body (or atom) incurred a mass decrease of (E/c^2). And that now seems experimentally correct for that class of actions, and that seems supported by NIST data!

(Because the electrostatic force between a proton and electron is about 10^{36} times stronger than the gravitational force, the Bohr atom can likely reveal to us some important concepts easier and less expensively than some other means. Easier than difficult astronomical tests likely associated with the General or Special Theories of Relativity. And the Bohr atom is, so-to-speak, right under our noses and like a microcosm of the universe.)

Returning to that 9-27-1005 paper, I think Einstein broke new ground which was previously foggy at best, and he presented a very helpful overview. But somewhat related to all that was a paper by Niels Bohr about eight years later [4]. There, by tackling many of those internal and external dynamics of the hydrogen atom in detail, Bohr also broke new ground and discovered new, important, and valuable relationships.

2. Overview of Solution to Paradox

Now back to the main question. Why does a particle in some cases incur an increased mass after its velocity is increased – and yet, in a seemingly pretty similar case, it incurs no increase in mass after its absolute velocity is increased?

I believe that powerful accelerators, like the Van de Graaff generator and cyclotron, and probably the Betatron – externally bully the accelerated charged particles forward against an aether near the front face of the particle. It is sort of like being hit in the back by many powerful gamma rays (high energy photons) – one immediately after another. And that the aether near that front face during much of that forward acceleration is at least as pressurized and dense as that of average ethereal space. That leads to a different response regarding the increased speed of the particle and the resulting change of its mass – compared to that which results from a natural electrostatic attraction between an electron and proton. The latter accelerates and increases the velocities of the electron and proton toward each other in a "natural" way and in a natural, but special, environment. On the other hand, cyclotrons are like being in an airplane on an aircraft carrier and being quickly accelerated by a catapult to a high takeoff speed, and you feel the great discomfort of a very high "G" force!

So in contrast to that – a far away electron, being gently attracted to a proton, accelerates in a natural voltage gradient (a pressure gradient) toward the proton – with a naturally lower ethereal pressure and density in the region between them. I.e., on the faces of each that face each other. And, at most, just normal ethereal pressure and density are applied to their back faces, and even that pressure decreases as the electron gets nearer and nearer to the proton. So that, contrary to the case in the previous paragraph, no mass increase of the electron or proton need occur. And none seems to empirically occur, then. It is like gravitational free-fall, acceleration but the astronaut does not feel it.

I believe that long-lasting particles have spin that can also plays a key role regarding mass increase vs. travel velocity. Try to imagine yourself carrying a clock with a thin clock-hand having a very massive pointer at the end of its hand. Imagine the clock-hand and pointer rotating fast, say, even as fast as the speed of light. But, say, when your forward speed and that of the clock you are carrying reaches nearly the speed of light, the rotational speed of the clock-hand must nearly stop. I.e., otherwise the vector velocity of the clock pointer would exceed the velocity of light, "c". So, unless something special happens, the rotational angular momentum of the clock-hand must decrease to nearly zero. So unless something else happens to compensate for the slowing rotational

velocity (which would normally be expected to decrease the angular momentum) – the law of "conservation of angular momentum" will be violated.

So, roughly speaking, we'll just say that the violation of the law, here, is prevented by the following: The more slowly rotating clock-hand receives more mass from the mass of the aether or from the mass of hitting photons, and thus the clock-hand incurs a mass increase! And thus the clock-hand can now rotate slower, but its added mass will tend to support its former appreciable angular momentum. And thus conform to the conservation of angular momentum law. Now that description may not be perfect, but it may help us visualize why the accelerated particle or clock-hand gains mass, under the conditions somewhat like presented. (And thus the slower rotation of the clock-hand seems to cause time to slow down when the forward travel velocity of the clock is increased.)

Now, back to the case of the simple electron being attracted to the proton and moving toward it or beginning to orbit it. As it does so, the ethereal region from its far face to its near face (the gradient encountered) is going from slightly less than a normal pressure and density – to even less than that! Under those conditions, perhaps the electron's spin can slightly exceed the speed of light or its radius may increase. Thus, the electron can LOSE a tiny percent of its mass and still maintain the same angular momentum as a free electron at rest. (More on that later.)

That situation, in a major way, is opposite the situation of "the high G catapult" test described earlier. The case of "electrostatic attraction" is likely much like "gravitational attraction". That is – when you are dropped in a gravitational field and thus are accelerated downward, faster and faster, you experience a DRIFTING weightlessness. I.e., that is like "free-fall", instead of feeling great pressure against your back like the "catapult"!

But even in the earlier described, lower pressure and lower density aether cases, say, if you suddenly hit high density water, your mass might increase until you assumed a slower rotational spin and better hydrodynamic shape. After that, per this attempted analogy, your mass need no longer increase.

We will discuss later the behavior of a photon, an entity that responds differently than a typical particle described above. And for that and related reasons – I think the photon should be considered a "pseudo-particle".

3. Miscellaneous Holistic Comments

There seems to me to be about four major classes of phenomena occurring – that relate possible velocity variation with possible mass variation. But those uniquely challenge most of us to understand them because of their simplistic description. We will only tackle a few of them in some detail in this limited space paper:

Class 1: The mass and energy of the photon changes as it is going into (or out of) a gravitational field, even though its speed does not change!

I think we learn, at least in that case, that those photons (pseudo-particles) change in mass, even though their speed holds constant. And that in each such event, even the directly measurable (mc^2) energy and (m) mass do not likely hold constant. That is because the photon, and also the body that is gravitationally attracting it, likely both gain a "small tad" of mass and energy. And we should likely accept that these challenging events occur because a hidden aether has mass, and can transfer real mass, as well as energy, to a pseudo-particle, i.e., a photon. (And aether can also receive mass from the photon – after the photon finishes its pass close to the attracting body and leaves that region.) I believe those actions happen and are contrary to the limited notion of a "superfluous aether", the term Einstein used in his 6-30-1905 paper.

So I think that aether has potential energy and useful mass. ((Even before the very helpful $E = mc^2$ by Einstein (instead of $E = 0.5mc^2$), and before the concept of particle spin – Hertz, in his last work, cautioned the following: "If we try to understand the motions of bodies around us, and to refer them to simple and clear rules, paying attention only to what can be directly observed, our attempt will in general fail" [5].))

A sometimes overlooked implication of the two paragraphs above is this: Suppose a photon likely gains and then loses a tiny part of its total mass when it passes near a gravitational body, on its way to a more distant absorbing target. Thus, even though the same total amount of mass of the photon – that left the emitter – may finally arrive near its target, some of that arriving photon mass is NOT its original. And that is a major aspect of "what makes a wave a real wave" instead of a pure traveling particle, an aspect or paradigm that is seldom mentioned or well-discussed in textbooks. And perhaps for some very long, special routes traveled by photons – maybe almost all of its mass that it delivers to the target, is "newly substituted mass" in place of the old lost mass. If we wisely accept that aether does have mass and various sorts of capabilities (such as changing the photon's mass) – then that will greatly enhance our understanding of some other mysterious physical events, too.

Class 2: Free Neutron decay, which results in production of a proton and electron, and the electron flies away from the scene. But in one somewhat extreme case, the electron flies away at nearly the velocity of light, with its mass increased (and thus equal to about 2.5 times that of a rest mass electron). That is nearly the mass difference between a free, at-rest, neutron and the proton left behind in such free neutron decay. But in another contrasting and pretty extreme case of free neutron decay, the electron barely gets away and only at a slow speed and without a significant increase in its mass. And many physicists try

to maintain the wished-for conservation of mass and energy, despite the different case behaviors, by supposing that a strange, hard-to-find anti-neutrino is also emitted in the decay. In one case they postulate a low-mass anti-neutrino, and in the other case a much higher mass anti-neutrino. Regretfully, we cannot address this interesting and challenging dichotomy in detail in this limited paper.

Class 3: Electron-Positron Annihilation – where an electron and positron, orbiting each other, converts to a pair of photons and each photon flies away from the scene. Each departing photon has a neutral mass equal to each mass of the original mutually orbiting particles before they "annihilated". Again, we cannot address this interesting event in detail in this limited paper.

Class 4: The Bohr atom and its actions have already been previously described to some extent. And in some ways that applies to other atoms with many protons in their nucleus, but stripped of all orbiting electrons except for just one electron. And that one electron might be "pulled" toward such a nucleus, say, a nucleus containing 83 protons – to orbit it at well over half the speed of light and also in a very near orbit! (The latter paradigm has too deep of indirect implications to fully discuss in this paper, especially if its nucleus consists of 83 or more protons.)

One problem with the Bohr atom is that a very "small chip" of mass seems to have been stolen from its orbiting electron and proton – for building that photon that flew away from the scene. That is the logical conclusion based on NIST data and other considerations. But it is the full original mass of the electron that is envisioned as orbiting – in the textbook Bohr model presentations. And if that full electron is not used, an extremely small error will seemingly arise, even if too small to measure. Of course, one might envision a small electromagnetic action between the very slowly orbiting proton and much faster orbiting electron – as neutralizing some or all of that possible error. Or that in combination with other factors – maybe the proton lost the small chip of mass. But we will let that discrepancy to be pursued by some talented specialist, if interested.

Other Remarks: Now, think of the large number of atoms and molecules in the universe with orbiting electrons due to "natural" charge-related attractions! And the nucleons that lose a small percent of their mass during nuclear fusions and may have fast orbits or other special motions in the nucleus. (And maybe neutral or charged particles or bodies orbiting a large body due to gravity. However, their angular momentum would then drastically exceed that of the Bohr hydrogen atom's electron. And thus the mass loss paradigm may not apply to the gravity case involving greatly separated orbiting, i.e., great distances compared to the hydrogen atom's "small quantum world".) But still, the percent of particles that have experienced a mass decrease, despite their increase in speed – may be appreciable compared to those incurring a mass increase with increase in their speed. Perhaps an important balancing principle maintaining and driving our universe as we know it.

I think a lot of special phenomena arise in the universe because it is not totally occupied by an "ultra low density aether" alone, but instead a small percent of space is occupied by rather compact, high density mass particles. And that the aether flow increases in velocity and decreases in pressure as aether flow tries to squeeze between those particles. And that slight "Venturi" pressure reduction, the Venturi effect, is the source of, at least, attractive nuclear forces. (And other types of ethereal flows might occur, perhaps cyclone-like and anticyclone-like.)

In a sense, Chemistry, with its formation of atoms with orbiting electrons and their ionization energies – may be just a microcosm version of nuclear physics phenomena, with its drastically larger nuclear fusion energies. But both actions arise from a similar cause, I think. There is a very slight occupancy–related congestion of ethereal space that arises, even between a proton and a small electron in the ground state of the Bohr orbital model. And that arises even though they have about a $0.53x10^{-10}$ meter separation. But there is a much greater occupancy congestion between nucleons in a nucleus, say with only small grooves between nucleons. I.e., about $1x10^{-15}$ meter between nucleons. Thus, a much greater Venuri-flow attraction or the like – with the much lower ethereal pressure developed between nucleons, in the case of nuclear forces.

Optional remark: A very rough description of the Einstein General Theory of Relativity is sometimes given by picturing a knitting or fabric of "space–time" as becoming deformed or curved near two bodies that are close together. But I prefer, instead, to picture the flow of aether as curved or deformed between those bodies. And perhaps something like a Venturi effect (relative pressure reduction) or attraction thus arises between those bodies.

To avoid excess length, we will skip roughly modeling a fragile photon vs. a sturdier electron or proton. And just discuss the following basic difference between the photon and the basically more sturdy electron or proton:

First, based on the work of A. H. Compton on x-ray or photon deflection, we can surmise the following: Imagine that a photon travels in an overall pretty straight line, except for being deflected, first, somewhat to the left and then back an equal amount to the right, and that that shuffling occurs, say, fifty times. And that those deflections were caused by encountering electrons at rest, or moving slowly – close to its path. After that, the photon could likely have almost no mass and energy remaining. But that outcome cannot happen with a STURDY proton or electron traveling that path. Regardless of the deflections along the way, and regardless, after that, of whether it is traveling at its original speed or zero speed, the out-

come is different from the photon case. The final elementary particle will still have, roughly speaking, its standard "rest-mass" or perhaps an even greater "relativistic" mass. That sturdiness differentiates a conventional real particle from a photon pseudo-particle.

Back to the photon. If the photon must maintain a constant speed, c, while moving toward the source of the gravity pressure gradient; it is not free to undergo the natural adjustment of "speed change under acceleration forces". And thus maybe avoid a change in mass – an option available for a conventional particle. So that, more than otherwise – the photon may experience a greater pressure against its back as it gets closer to the source of the attracting potential gradient. In other words, we can likely expect it to behave differently from a conventional particle.

One crucial last important point: The proposition of a very energized and thus high-pressurized, low-density aether – leads to the following expectation regarding a high-density compact, stable particle mass in the aether: Imagine a small volume region that is somehow temporarily devoid of mass, aether, and its pressure. And, say, that vacuum amounts to 10^{-45} cu. meters, about the volume of a compact proton. Then there is a modest limit as to the velocity, energy, and angular momentum that a proton can acquire by being sucked into such small, limited volume. Or likely even a smaller volume. But contrast that with what can happen over the vast ethereal space outside of that small volume. Since energy can equal the product of roughly "pressure times volume", there is almost no limit as to how much energy a high-density conventional particle can acquire when accelerated to high velocity through vast space! I.e., especially if the high-density particle faces a normal density aether in front of it and some of that aether sticks to it. And that is the ultimate reason why, even in powerful nuclear fusions, the nucleons lose only about 1 percent of their original, free particle masses. But with cyclotrons and the like, then formerly "at-rest" particles can see their mass increased by about 100 times.

That is the greatly important reality that we witness in the experimental world. And I do not think that that outcome can be rationalized, instead, by trying to model a universe where all or most of space is devoid of any aether! (And like a fish adapted to water, or gravity that we are so accustomed to, what would be the strongest evidence for a certain conclusion – is evidence often overlooked. I.e., because we are so adapted to what would otherwise seem strange.)

4. The NIST data – likely accurate enough

I found it difficult to surf through the NIST website efficiently to find the various data below, including trying to choose effective words to put into their search window. But I finally found it there [6]. Below is the relevant data I found. And how I works with it is shown adjacent an asterisk:

Free electron mass: 0.00054857990946(22) u

Free proton mass..: 1.007276466812(90) u

*Total of above free (separate) masses. .....:1.007825046721 u

But note the following: (H-1), or "Hydrogen-1", has the mass.....:1.00782503223(9) u

(That is the "Bohr atom" in its ground state as author found by surfing the NIST website 9-7-2015.)

*Note the SUM of the masses of the Individual (independent) "free" parts EXCEEDS the Mass of (H-1), or "Hydrogen-1" atom by the following difference between the above.....: 0.0000000145 u

Even without a lengthy discussion regarding the accuracy, the parentheses, and statistics associated with the above, I think we can fairly say this: Regarding the amount by which the the mass of Hydrogen-1 empirically seems to differ from the very greatly separated free, at rest proton plus electron, 0.0000000145 u, we conclude this: It is unlikely that the '4' in that sequence, '145', will change. But even if it would change from 4 to 5, or from 4 to 3, we would still have the seemingly reliable empirical fact that Hydrogen-1, the Bohr atom, decreased in mass when formed!

In the Bohr electron model and theory, the ground state orbital electron velocity is calculated as $0.022x10^8$ meter/sec. That is a little less than a hundredth of the speed of light, 'c'. If a free, at rest electron were speeded up to $0.022x10^8$ meter/sec. in 'free space' (not by attraction to the proton) its then theoretical 'relativistic mass gain' would approximately equal the mass lost by the Bohr Hydrogen atom (H-1) when formed. I.e., formed from its formerly at rest, unbound parts. That seems indicated by the NIST data above, even though it may seem a little surprising. That much mass lost is also approximately equal to the 'equivalent mass' of the photon which (H-1) emitted when formed, and is equivalent to the energy that that emitted photon has when it flew away from the scene at velocity 'c'. (We skip displaying the 'conventional relativistic calculations' here to shorten and simplify the paper).

Now remember this: The kinetic energy of the high velocity orbiting electron plus the total "mc^2 " energy of the emitted photon was prompted or provided by "the potential electrostatic energy lost" when the orbital system was formed. I.e., the electron and proton orbital system was formed when the electron "jumped" into the "ground state orbit" – after the electron had been previously drifting slowly a great distance from the proton.

((The above outcomes support rather well the groundbreaking discoveries arising from the Bohr atomic theory, model and treatment (at least with regards to the magnitude of the equalities that Bohr calculated). And as also presented in many long-standing respected text-

books. That is very good, despite at least one drawback in that Bohr atomic model, as follows: It is likely that not quite all of the full rest mass of the electron, that was originally a long distance from the proton, was carried with it when it became the orbiting electron in the Bohr atom. So there may be a very slight theoretical problem with the standard textbook treatment of the Bohr atom. So imagine that a very small chip off the orbiting Bohr electron or proton was donated to make the photon mass. Then, roughly, if we multiply that donated mass by c^2, we obtain the total energy that the photon has when created and emitted.))

5. Conclusion and Summary

A reasonable interpretation of "NIST" data and other considerations have now led this author to change some of his opinions that he expressed earlier in a few papers. He now regards it as thus very likely that the Bohr hydrogen atom, especially in its ground state, has less mass than the sum of the rest masses of a proton plus a slowly drifting, far away "free" electron. This may seem surprising since it implies that the speedily orbiting electron has not only failed to incur a "speed-related relativistic mass increase". That electron, and perhaps the proton, have also lost mass by donated it to make the photon that flies away from the scene! (That may mean that there is a very slight unexplained discrepancy in many textbook presentation of the Bohr atomic model.)

Since that photon has received a total energy "E" from the orbital system it left, then according to the Einstein 9-27-1905 paper, the emitting body or system suffers an (E/c^2) worth of mass reduction. (So the mass of the Bohr atom was decreased by that, and apparently the photon flew away with that donated mass. And thus – the shortest of two papers by Einstein in 1905 is likely applicable and suitable here.)

So the two above paragraphs prompt this question: How can a particle, accelerated to a high velocity, say by a cyclotron, incur a great mass increase – and yet an electron, attracted to a proton and thus accelerated to a high velocity, not incur a mass increase? In fact a mass decrease after providing the mass for the deporting photon!

We propose this: Very stable, very compact protons and somewhat less compact electrons occupy at least some space in the otherwise very low-density, highly energized ethereal space of the universe. So naturally, ethereal flows develop, and its flow speeds up while trying to squeeze between particles – like the electron and somewhat close proton. Thus, a natural Venturi flow effect arises, i.e., an "attraction-like" force between particles or bodies, a natural potential energy gradient.

That special "voltage pressure gradient" has less than normal ethereal pressure between the attracting particles, but a closer to normal pressure on the far faces of the particles. That contrasts with being unnaturally hit hard in the back by many gamma rays and thus knocked forward even against average or higher-than-average pressure against the front face of a particle or body.

And the feeling of a catapulted aircraft carrier pilot vs. the different feeling of a space astronaut in-training – illustrates the different feelings, experiences and realities above: First, the very uncomfortable high G force of a powerful "catapult forward", as an airplane is launched from an aircraft carrier. But, in contrast, when under gravitational "free–fall", the astronaut is drawn faster and faster toward, say, Jupiter – but he then feels no force, i.e., like just drifting "weightlessly".

Roughly, that is why some stable bodies, (those that maintain at least a substantial minimum mass at all times – like the proton and electron) gain great mass when "bullied" forward by the cyclotron against a normal pressure ethereal region. Or when they enter such normal pressure ethereal region after the cyclotron push.

There are many other questions and propositions that might be prompted by the major subject of this paper, and ideas for testing of them, too. But we could only touch on a few in this paper. For example, a photon under gravity may likely gain or lose some mass without incurring a speed change. But the photon is sort of a 'pseudo-particle' and not in the same class of particles as the sturdy proton and electron. For example, if a photon bounces gently off a thousand separated electrons at rest, as is imaginable in Compton-like experiments, the photon has no significant minimum mass left after that. But even in nucleon fusions, the nucleons and nucleus retain about 99 percent of the rest mass of the particles from which they ultimately originated. And if, in exothermic chemical reactions, there is still much less mass lost – maybe chemical reactions are just small microcosms of nucleon fusions.

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