

A discussion on the electromagnetic mass of electrons

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Abstract: The issue of the electromagnetic mass of electrons remains an unresolved problem in physics. Traditionally, it has been believed that the electromagnetic mass of electrons naturally constitutes a part of their rest mass (i.e., 9.11×10^{-31} kg). In recent years, a new and opposing viewpoint has emerged, suggesting that the electromagnetic mass of electrons is not a component of their rest mass (i.e., 9.11×10^{-31} kg). This perspective has now garnered substantial support from both theoretical and experimental evidence. Undoubtedly, the exploration of the electromagnetic mass of electrons inevitably touches upon many aspects of physics, such as electron spin. Therefore, while explaining the new viewpoint, necessary clarifications and discussions on these related topics are also provided.

Keywords: Electrodynamics, Electron, Electromagnetic Mass, Special Relativity

1. Introduction

In 1897, J.J. Thomson's discovery of the electron was of extraordinary significance [1,2]. Alongside this discovery, the issue of the electromagnetic mass of electrons has existed for a long time and remains unresolved to this day [3,4]. This problem can be traced back to around 1900, before the birth of Einstein's Special Relativity in 1905. However, to date, the highly anticipated quantum theory has still not succeeded in calculating the electromagnetic mass of the electron. This issue is mentioned or discussed in general electrodynamics textbooks [5-10] and even in many electromagnetism textbooks, highlighting its significant place in physics.

In the long history of exploring the electromagnetic mass of electrons, the notion that the electromagnetic mass is a component of the rest mass (9.11×10^{-31} kg) has seemingly become a fixed mindset. In recent years, a new perspective on this issue has broken free from this conventional thinking. This new viewpoint asserts that the electromagnetic mass of electrons is not a component of their rest mass (9.11×10^{-31} kg). The new perspective has already found substantial theoretical support and some compelling experimental evidence. In the spirit of academic diversity and the principle of "letting a hundred schools of thought contend" — with the aim of stimulating further discussion — regardless of the correctness of this new viewpoint, the author merely seeks to explore it along with its supporting arguments.

2. Traditional understanding of the electromagnetic mass of electrons

The electron inherently possesses an elementary charge. The field associated with this charge is referred to as the electron's own electromagnetic field, and the mass corresponding to the energy of this electromagnetic field is what is known as the electromagnetic mass of the electron. The specific basis for defining electromagnetic mass lies in the correspondence between mass and energy in the Special Theory of Relativity (i.e., the famous equation $E = mc^2$). Initially, people imagined the electron as a uniformly charged sphere (or spherical shell) and considered the energy of its corresponding electromagnetic field as the primary source of the electron's rest mass m_0 (i.e., 9.11×10^{-31} kg, the same applies below). Based on this, the radius of the electron r_0 was estimated to be approximately 2.82×10^{-15} m. This is the so-called classical electron radius. Of course, it is now understood that the classical electron radius r_0 is not the actual size of the electron, but it is regarded as a limit to the applicability of classical electrodynamics [5,8,9].

At the same time, because the electromagnetic mass was viewed as a natural component of the electron's rest mass m_0 , and the two were considered inseparable and indistinguishable, it was long believed impossible to measure the electromagnetic mass of the electron experimentally.

Naturally, this is only half of the story, and this half is more or less mentioned in general electrodynamics textbooks. Next, we will explain the other half of the story, which is relatively less discussed in the literature. It has long been assumed that the electrostatic field of the electron possesses spherical symmetry. Based on the framework of Special Relativity in electrodynamics, the electromagnetic field energy of a spherically symmetric charge distribution moving with a uniform velocity v can be derived as:

$$W = \gamma \left(1 + \frac{1}{3} \frac{v^2}{c^2}\right) W_0$$

[7,8,11,12] and the momentum as:

$$P = \frac{4}{3} \gamma \frac{W_0}{c^2} v$$

[7,8,13,14], where W_0 is the electromagnetic field energy of the charge distribution at rest, and the relativistic factor $\gamma = 1/\sqrt{1-v^2/c^2}$. Different literatures present significant variations in the mathematical derivation or approach to these formulas, yet they converge to the same result.

Defining $\frac{W_0}{c^2}$ as the rest mass of the electromagnetic field m_{EM0} , the electromagnetic mass and momentum of the charge system can be expressed as:

$$m_{EM} = \gamma \left(1 + \frac{1}{3} \frac{v^2}{c^2}\right) m_{EM0}$$

and

$$P = \frac{4}{3} \gamma m_{EM0} v$$

This result greatly surprised people. Since electromagnetic mass was considered a component of the electron's rest mass m_0 , it was naturally expected that the energy and momentum of the electron's electromagnetic field would change synchronously with its relativistic energy and momentum when the electron moves. In other words, the mass formula for the electromagnetic field should take the familiar form $M = \gamma m_0$, and the momentum formula should be $P = \gamma m_0 v$. This unexpected inconsistency sparked extensive and enduring theoretical speculations and attempts to modify the relevant theories, such as Poincaré's Stress Tensor theory [8,15], the nonlinear electrodynamics theory of Born and Infeld, and the advanced potential theory proposed by Dirac, among others. These theories lack experimental support, face significant challenges, and are incompatible with one another. Related theoretical speculations and attempts go far beyond these [4,14,16,17], yet ultimately, none of the theories (including quantum theory) have provided a numerical measure of the electromagnetic mass of the electron.

Therefore, to this day, the relativistic total energy and total momentum of the electron are still simply expressed as $E = \gamma m_0 c^2$ and $P = \gamma m_0 v$, completely overlooking the possible distinction between the electromagnetic mass of the electron and its rest mass.

The author believes that this situation arises because people's thinking is constrained by the fixed mindset that "the electromagnetic mass is a component of the particle's rest mass." For convenience, this fixed mindset—"the electromagnetic mass is a component of the particle's rest mass"—will be referred to as the "field energy inclusion" theory.

3. New perspectives on the electromagnetic mass of the electron

3.1. Proposal of the "Field Energy Non-Contribution" theory

In recent years, a new perspective has emerged regarding the electromagnetic mass of the electron, asserting that "the electromagnetic mass of the electron is not a component of its rest mass ($9.11 \times$

10^{-31} kg)." This viewpoint breaks free from the aforementioned fixed mindset and will be referred to as the "field energy non-contribution" theory.

3.2. Support from theoretical and experimental evidence

The breakthrough of the "field energy non-contribution" theory from the aforementioned fixed mindset occurred entirely by chance. Initially, in 2011, based on the formal similarities between Coulomb's law and Newton's law of gravitation, Reference [18] posited that mass, as a source of gravitation, should possess relativistic invariance similar to electric charge. Consequently, Reference [18] decisively proposed the academic hypothesis that "rest mass in the sense of special relativity is the source of gravitation" (this hypothesis also predicts the existence of gravitational waves). One direct corollary of this hypothesis is that the energy (mass) of electromagnetic and gravitational fields does not contribute to rest mass (i.e., the gravitational source). In other words, this hypothesis suggests that the physical nature of electromagnetic field energy (mass) and rest mass is entirely distinct.

Shortly thereafter, inspired by Reference [19], References [11] and [13] derived the formulas

$$W = \gamma(1 + \frac{1}{3} \frac{v^2}{c^2})W_0$$

and

$$P = \frac{4}{3} \gamma \frac{W_0}{c^2} v$$

through mathematical deductions that differed from those in other literature. Compared to other references, the mathematical derivations in References [11] and [13] are more accessible and provide a more thorough explanation. More importantly, these references no longer regard the inconsistency between these two formulas and the well-known formulas

$$E = \gamma m_0 c^2$$

and

$$P = \gamma m_0 v$$

was surprising but instead treat it as a natural consequence. This serves as strong theoretical evidence for the "field energy non-contribution" theory. Encouraged by this, numerous theoretical and experimental pieces of evidence supporting the "field energy non-contribution" theory have been discovered, gaining momentum rapidly.

In fact, the issue of "the relationship between electromagnetic mass and rest mass" is broad and significant, and it can be studied independently of gravitational field research. In other words, the validity of the "field energy non-contribution" theory is unaffected by the correctness of the aforementioned gravitational hypothesis. As far as publicly available literature is concerned, the perspective of "field energy non-contribution" possesses originality.

3.3. Relativistic calculations of electromagnetic field energy and momentum

Based on the widely accepted relativistic transformation formulas for electromagnetic fields between different inertial frames, the energy or momentum of electromagnetic fields in various forms of motion has been successively calculated. These results, along with the formulas $W = \gamma(1 + \frac{1}{3} \frac{v^2}{c^2})W_0$, $P = \frac{4}{3} \gamma \frac{W_0}{c^2} v$, serve as theoretical foundations for the "field energy non-contribution" theory:

Reference [20] shows that the electromagnetic field energy and momentum of a charged spherical surface, a cylindrical capacitor, a current-carrying solenoid, and a parallel-plate capacitor moving in specific directions exhibit distinct characteristics. Particularly noteworthy is the case of the parallel-plate capacitor moving perpendicularly to its plate surfaces, where the electromagnetic field energy decreases as the velocity increases, while the momentum remains zero.

Reference [21] indicates that the average energy and average momentum of the electromagnetic field over one cycle in a uniformly moving parallel-plate open optical resonator depend on the direction of the cavity's motion.

Reference [22] demonstrates that the energy and momentum of electromagnetic fields with different wave modes in a uniformly moving rectangular resonant cavity vary significantly and are related to the wavenumber (the magnitude of the wave vector).

Reference [23] reveals that for capacitors and solenoids filled with dielectric materials moving in specific directions, the electromagnetic field energy is also related to the relative permittivity and relative permeability of their respective filling media.

Compared to the well-known formulas for rest mass, $E = \gamma m_0 c^2$ and $P = \gamma m_0 v$ (note: the energy or momentum expressed by these formulas is only a function of velocity), the aforementioned theoretical research results, while not fully proving the correctness of the "field energy non-contribution" theory, undeniably provide sufficiently strong theoretical support for it.

The relativistic transformation of electromagnetic fields between different inertial frames reflects the unity and opposition between the electric and magnetic fields within the electromagnetic field itself. At this point, we cannot help but wonder: does the existence of this internal unity and opposition imply that the physical nature of electromagnetic mass and rest mass is fundamentally different? Furthermore, could the relativistic transformation of the four-dimensional wave vector $k_\mu = (\bar{k}, i\frac{\omega}{c})$ in special relativity, which explains the phenomenon of astronomical aberration, also serve as theoretical evidence for the "field energy non-contribution" theory?

Simultaneously, the author has been actively searching for experimental evidence supporting the "field energy non-contribution" theory, with notable findings:

Reference [24] indicates that the results of Mr. Ji Hao's series of electron acceleration experiments also deviate from the theoretical predictions of the "field energy inclusion" theory. Many researchers have used this as a basis to question or even refute special relativity.

Reference [25] shows that under certain conditions, the experimental data from Compton scattering exhibit significant systematic deviations from the theoretical expectations of the "field energy inclusion" theory, while the "field energy non-contribution" theory offers a more reasonable explanation for these deviations.

Reference [26] demonstrates that the analysis of data from the Bertozzi experiment suggests that the "field energy non-contribution" theory appears more plausible than the "field energy inclusion" theory.

It is worth noting that in references [25] and [26], the mass of the electron is divided into electromagnetic mass and non-electromagnetic origin mass. When the electron is in motion, the energy and momentum of its electromagnetic mass are calculated using the formulas $W = \gamma(1 + \frac{1}{3}\frac{v^2}{c^2})W_0$ and $P = \frac{4}{3}\gamma\frac{W_0}{c^2}v$, while the energy and momentum of its non-electromagnetic mass are calculated using the formulas $E = \gamma m_0 c^2$ and $P = \gamma m_0 v$. Based on this approach, the experimental data from Compton scattering and the Bertozzi experiment were interpreted and analyzed, yielding some quantitative results regarding the electromagnetic mass of the electron.

3.4. Limitations of existing evidence and future prospects

In summary, the "field energy non-contribution" theory has also gained some quite compelling experimental evidence, from which preliminary quantitative results regarding the electromagnetic mass of the electron have been derived. However, the experimental data and their analytical conclusions currently available in the published literature are not yet sufficient to be convincing. Firstly, the amount of relevant data is too limited to meet the need for mutual verification among datasets. Secondly, these experiments are constrained by their objectives and measurement methods, making the data less scientific or precise. For example, the Bertozzi experiment aimed to produce an educational film promoting special relativity. It only needed to clearly reject the velocity-kinetic energy relationship of particles in Newtonian mechanics and qualitatively support the mass-velocity relationship in special relativity. High precision in experimental data was not required, and Bertozzi himself did not deny the significant errors in his data.

Another example is Mr. Ji Hao's series of electron acceleration experiments, which were designed to challenge special relativity, and the associated experimental data have often been met with skepticism. The author believes that if a sufficient amount of reliable and credible experimental data can be obtained through trustworthy measurements, the "field energy non-contribution" theory will undoubtedly provide a quantitative result with considerable credibility on the issue of the electromagnetic mass of the electron. This would offer a highly credible reference for subsequent research and other related studies on electrons, such as free-electron lasers.

4. Clarifications on the new perspective

Regarding the numerous theoretical and experimental pieces of evidence for the "field energy non-contribution" theory, as well as the research on the electromagnetic mass of the electron in references [25] and [26], the following points are further clarified:

4.1. The issue of spherical symmetry of the electron

In references [25] and [26], it is assumed that the electrostatic field of the electron possesses spherical symmetry. In fact, it has long been naturally assumed that the structure of the electron is highly spherically symmetric. General references [13-15] also assume spherical symmetry in the electrostatic field of the electron when discussing related issues. To date, no experiment has directly negated the spherical symmetry of the electron's structure, even though current experiments can probe scales as small as 10^{-18} m, which is far smaller than the possible distribution scale of the electron's electrostatic field (i.e., the classical electron radius).

4.2. Theoretical applicability and research self-consistency

Does the calculation of the electron's electromagnetic field exceed the scale of classical electrodynamics? Through a comprehensive analysis of experimental data in the published literature, we anticipate that the ratio of the electron's electromagnetic mass to its rest mass is around 0.05 (due to a printing error, the value "0.365" in the sixteenth line from the bottom of the right column on page 41 of reference [25] should actually be "0.0365"). Even if this ratio were to increase severalfold, for example, to 0.2, the corresponding possible distribution scale of the electron's electrostatic field would not exceed the applicable range of classical electrodynamics.

4.3. Compatibility of research results with existing knowledge

First, neither the "field energy non-contribution" theory nor the studies in references [25] and [26] fabricate or invent any new physical concepts; they are merely an organic combination or natural extension of existing logical knowledge. Therefore, although the "field energy non-contribution" theory and the research in references [25] and [26] involve modifications to existing logical frameworks, they are not fundamentally a negation of the existing system of knowledge but rather a supplementation to address gaps and omissions.

Second, as mentioned earlier, through the studies in references [25] and [26], the author anticipates that the ratio of the electromagnetic mass of the electron to its rest mass is approximately 0.05. Considering that the rest mass of the electron is about 1/1800 that of a proton or neutron, for macroscopic objects, the electromagnetic mass constitutes less than 1/10,000 of the total mass and is likely negligible. For microscopic particles, while a ratio of around 0.05 is not insignificant, direct measurements of the mass of individual microscopic particles are challenging, and they are often indirectly understood or represented through other physical quantities (such as wavelength). As a result, a ratio of around 0.05 may also be concealed. The analysis of experimental data from Compton scattering in reference [25] clearly illustrates this issue. In fact, if one is not misled by the superficial representation of Bertozzi's experimental diagrams but instead delves into the calculations of Bertozzi's experimental data and compares them with the "field energy inclusion" theory on which Bertozzi relied, underlying problems become apparent.

In summary, the "field energy non-contribution" theory and the research in references [25] and [26] exhibit a high degree of compatibility with existing knowledge.

Although the expected numerical value for the electromagnetic mass of the electron may be small, it could still trigger a series of logical consequences in theory. This issue should not be viewed in isolation but rather examined within the broader historical development of physics. The history of physics has always been one of continuous innovation and renewal. Despite the extraordinary achievements of modern physics, many fundamental problems remain—issues that can be described or calculated using mathematical formulas but whose underlying physical essence is not yet fully understood. Examples include the occasional failure of Newton's third law in electromagnetism, the AB effect demonstrating the observable physical effects of the magnetic vector potential, and the structure and stability of the electron. By delving into the "relationship between electromagnetic mass and rest mass," we recognize the necessity and possibility of connecting and integrating these fundamental issues for resolution. In fact, the academic hypothesis proposed in reference [18], which posits that "rest mass in the sense of special relativity is the source of gravitation," has already skillfully and naturally combined the most essential theoretical ideas of Newton, Einstein, and Maxwell.

It is generally believed that the electron is a microscopic particle whose behavior should be described by quantum mechanics or quantum field theory. Thus, can the electromagnetic mass of the electron be discussed using approaches other than quantum mechanics or quantum field theory? This has been addressed in references [25] and [26], and due to space constraints, it will not be repeated here. However, it is worth adding that the relationship between the electromagnetic mass and the rest mass of the electron reflects its fundamental characteristics and should exhibit a high degree of stability. Therefore, whether viewed from a microscopic quantum perspective or a macroscopic classical perspective, this relationship should and must manifest relatively consistently.

4.4. Regarding electron spin

First, the spin of the electron is not a "rotation" of its structure but an "intrinsic" state, which is a consensus in quantum mechanics [27]. This "intrinsic" state does not inherently conflict with or oppose the spherical symmetry of the electron. Second, according to quantum measurement theory [28], when an experiment detects that an electron has spin in a specific direction, the electron is already in a state that has "collapsed" under the influence of the measurement environment. The author believes that a free, independent electron before state "collapse" still possesses spin, but its spatial orientation remains isotropic—i.e., spherically symmetric. Thus, the spin of the electron does not disrupt the spherical symmetry of the free, independent electron's structure. Third, although the electromagnetic field of the electron is related to its anomalous magnetic moment due to spin [29], the numerical value of the anomalous magnetic moment is relatively small. The author believes that even if electron spin has some influence on the electromagnetic mass research in references [25] and [26], such influence is not decisive but rather corrective—an issue to be addressed in the future.

4.5. From the perspective of gravitational research

Undoubtedly, the rest mass of an object should be a component of the source of gravitation. Therefore, if electromagnetic field energy contributes to rest mass, then electromagnetic mass would also be a source of gravitation, and photons (such as gamma photons) would necessarily be sources of gravitation. If this were true, it would be difficult to imagine the physical scenario: a gravitational source like a photon moves at the speed of light while the gravitational interaction between the photon and other objects also propagates at the speed of light? There are no light or electromagnetic wave radiation sources that can move at the speed of light, making it unlikely for a gravitational source to do so. Conversely, assuming that electromagnetic field energy does not contribute to rest mass, photons (such as gamma photons) would not be sources of gravitation and thus would not participate in gravitational interactions. In this case, the bending of light would no longer be a direct response of photons to other gravitational sources but could instead be a purely spatial curvature effect [30]. This would better connect the phenomenon of light bending with the purely spatial curvature effect, aligning more closely with the original intent of general relativity. Therefore, from the perspective of the "field energy non-contribution" theory, the logical conclusion that the rest mass of a photon is zero avoids the inference that "a gravitational source can move

at the speed of light" while also linking to the revolutionary idea of "spatial curvature" in general relativity, achieving a harmonious resolution.

5. Conclusion

From the above discussion, it is evident that although the new argument that "electromagnetic field (energy) mass does not contribute to rest mass" differs fundamentally from traditional understanding, it is supported by both theoretical foundations and experimental evidence, making it worthy of in-depth exploration. Additionally, the quantitative results for the electromagnetic mass of the electron provided in references [25] and [26] should hold significant reference value.

6. References

- [1] Gao Feng, Shu Hengqi. J.J. Thomson and the Electron[J]. *Physics Bulletin*, 1997(4): 34-36.
- [2] Wang Yongli. The Thomson Father and Son and Physics[J]. *Physics Bulletin*, 2012(5): 116.
- [3] J.L. Jimenez and I. Campos. Models of the Classical Electron after a Century[J]. *Foundations of Physics Letters*, 1999, 12(2): 127.
- [4] F. Rohrlich. *Classical charged particles* [M]. 3rd Ed. Singapore: World Scientific Publishing Co. Pte.Ltd, 2007.
- [5] Yu Fuchun, Zheng Chunkai. *Electrodynamics*[M]. Beijing: Peking University Press, 2003: 252.
- [6] Guo Shuohong. *Electrodynamics (Third Edition)* [M]. Beijing: Higher Education Press, 2008: 259.
- [7] Zhang Zongsui. *Electrodynamics and Special Relativity (Second Edition, Rearranged Version)* [M]. Beijing: Peking University Press, 2013.
- [8] Cai Shengshan, Zhu Yun, Xu Jianjun. *Electrodynamics (Second Edition)* [M]. Beijing: Higher Education Press, 2002: 398.
- [9] Liu Jueping. *Electrodynamics*[M]. Beijing: Higher Education Press, 2004: 356.
- [10] Yin Zhen. *Electrodynamics (Second Edition)* [M]. Beijing: Science Press, 2005: 295.
- [11] Yuan Xinxin. Electromagnetic Field Energy of a Uniformly Charged Spherical Surface in Uniform Motion[J]. *China Basic Science*, 2012, 14(6): 37-38.
- [12] E. Comay. Lorentz transformation of electromagnetic systems and the 4/3 problem[J]. *Naturforschlung*, 1991, 46a:377.
- [13] Yuan Xinxin. Electromagnetic Field Momentum of a Moving Charged Spherical Surface[J]. *Physics Bulletin*, 2013(11): 19-21.
- [14] Timothy H. Boyer. Classical model of the electron and the definition of electromagnetic field momentum [J]. *Physical Review D*, 1982, 25(12): 3246.
- [15] John David Jackson. *Classical Electrodynamics (Third Edition)* [M]. Hoboken (NJ): John Wiley & Sons, Inc, 1998.
- [16] H. Kolbenstvedt. Electromagnetic self-mass of the classical electron: An alternative exploitation of Fermi's claim for rigid motion[J]. *Physics Letters A*, 1997: 234-319.
- [17] Iwo Bialynicki Birula. Classical model of the electron. Exactly soluble example[J]. *Physical Review D*, 1982, 28(8): 2114.
- [18] Yuan Xinxin. A Note on the Calculation of Gravitational Radiation from the Binary Pulsar PSR1913+16[J]. *China Basic Science*, 2011, 13(6): 12-13.
- [19] Yuan Xinxin. Exploratory Reflections on Gravitational Theory[J]. *China Basic Science*, 2012, 14(3): 22-24.
- [20] Yuan Xinxin. Energy and Momentum of Electromagnetic Fields for Slowly Moving Charged Bodies[J]. *Physics Bulletin*, 2014(10): 24-26.
- [21] Yuan Xinxin. Energy and Momentum of Electromagnetic Fields in Moving Optical Resonators[J]. *Laser Journal*, 2015, 36(11): 110-112.
- [22] Yuan Xinxin. Energy and Momentum of Electromagnetic Fields in Moving Microwave Resonators[J]. *Radar Science and Technology*, 2016, 14(2): 198-201.
- [23] Yuan Xinxin. Energy of Electromagnetic Fields for Moving Capacitors and Solenoids[J]. *Space Electronic Technology*, 2016(1): 20-23.

- [24] Ji Hao. Experiments on the Measurement of Electron Lorentz Force and Energy[J]. Engineering Science, 2006, 8(10): 60-65.
- [25] Yuan Xixi. Investigating the Electromagnetic Mass of Electrons Using Compton Scattering[J]. Gansu Science and Technology Horizontal, 2015, 44(5): 39-41.
- [26] Yuan Xixi. Investigating the Electromagnetic Mass of Electrons Using the Bertozzi Experiment[J]. Experimental Science and Technology, 2016, 14(2): 4-7.
- [27] Qian Bochu. Quantum Mechanics[M]. Beijing: Higher Education Press, 2006: 211.
- [28] Zhang Yongde. Physical Principles of Quantum Information[M]. Beijing: Science Press, 2006.
- [29] Yang Fujia. Atomic Physics (Third Edition) [M]. Beijing: Higher Education Press, 2000: 191.
- [30] Yuan Xixi. An Exploratory Explanation of Gravitational Redshift[J]. China Basic Science, 2013, 15(2): 11-13.