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A New Perspective on the Fine-Structure Constant: Insights from the π/γ Ratio and Electron Dynamics

Ittipat Roopkom [1,*], Pichet Wisartpong [2], Wirote Jongchanachavawat [1], Beverly F. Stout [3], Tawatchai Mayteevarunyoo [4] and Paramote Wardkein [5]

1 Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, Phetchaburi, Thailand
2 School of Electrical and Electronic Engineering, Mahanakorn University of Technology, Bangkok, Thailand
3 BME, and independent researcher, Delta State University, Cleveland, MS, USA
4 Department of Electrical and Computer Engineering, Faculty of Engineering, Naresuan University, Phitsanulok, Thailand
5 Department of Telecommunications Engineering, School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
* Correspondence: author: ittipat.roo@mail.pbru.ac.th

Abstract: The fine-structure constant, α, is a fundamental constant central to electromagnetic interaction strength and the behavior of atomic systems. Despite extensive study, the origin of α remains an open question. This paper explores a new approach by examining the connection between α, the electron's anomalous magnetic moment, and the ratio π/γ, where γ is a relativistic Lorentz factor. Specifically, we propose that α may arise from the electron's rotational dynamics at near-light speeds, represented by $\gamma \approx 430$. The electron's anomalous magnetic moment reflects deviations from Dirac's predictions, influenced by higher-order quantum electrodynamic (QED) corrections due to virtual photon exchanges and electron spin interactions. These interactions alter the electron's magnetic moment, giving rise to a slight discrepancy from the g-factor value of 2. By expressing α as the ratio π/γ, we investigate whether this relationship captures both the fine-structure constant's specific value and the QED corrections underlying the anomalous magnetic moment. Our findings suggest that α could be interpreted as a dimensionless outcome of electron spin and relativistic effects, with π/γ potentially explaining the approximate value of α as 1/137. This perspective proposes a unifying framework in which α emerges from intrinsic electron properties and relativistic corrections, linking quantum mechanics with special relativity. This approach may enhance our understanding of α and its role across fundamental physics, offering insight into the constants that govern particle interactions.

Keywords: The fine-structure constant; QED; anomalous magnetic moment; Lorentz's factor

1. Introduction

The fine-structure constant, α, is one of the universe's most significant and enigmatic constants, valued at approximately 1/137. This fundamental constant plays a crucial role in determining the strength of electromagnetic interactions, influencing the behavior of charged particles like electrons and protons. It shapes atomic structure, quantum electrodynamics (QED), and photon-matter interactions, with implications across diverse areas in physics, including quantum field theory and relativistic frameworks. One intriguing aspect of α is its dimensionless nature, making it universally applicable across various physical contexts. Despite advances in physics, the fine-structure constant remains an unsolved puzzle, both in its specific numerical value and as a profound challenge to our understanding of the fundamental laws of the universe [1–6].

In this paper, we propose a novel approach to understanding the fine-structure constant by exploring a potential relationship among the mathematical constant π, the electron's rotational

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dynamics, and relativistic effects characterized by the Lorentz factor. The electron's intrinsic spin significantly influences its interaction with electromagnetic fields [7,8]. Although electron spin is a quantum mechanical property, it can also be examined through a relativistic lens, particularly in high-speed scenarios where the electron's velocity approaches the speed of light. In such cases, the Lorentz factor (γ) modifies the electron's observed properties according to special relativity. At high velocities, the electron's effective mass and interaction with electromagnetic fields are altered, impacting how its rotation (or spin) is perceived.

Section 2 presents an in-depth analysis of the relationship between the π/γ ratio and the origin of the fine-structure constant. By examining the interaction between the electron's rotation and this Lorentz factor, we aim to investigate whether α can be derived from a ratio involving π and these fundamental relativistic corrections. We propose that α, which encapsulates the strength of electromagnetic interactions, may emerge from a ratio involving π, the electron's relativistically corrected rotation, and a specific Lorentz factor. In our approach, we introduce a Lorentz factor of 430, representing a relativistic correction that influences the electron's behavior. This correction may provide insight into why α has its specific value and its relation to deeper principles in quantum mechanics and special relativity.

Section 3 discusses the deviation of the electron's anomalous magnetic moment due to spin, which relates to the π/γ ratio, and Section 4 concludes the discussion. Ultimately, this paper seeks to advance the quest to demystify the fine-structure constant by proposing a new perspective that emphasizes the role of electron spin and relativistic effects, governed by the Lorentz factor, in determining the value of α. If successful, this approach could help bridge the gap between quantum mechanics, relativity, and the fundamental constants shaping our understanding of the universe.

2. The Relationship Between π/γ and The Fine-Structure Constant

The fine-structure constant, α, characterizes the splitting of atomic spectral lines, first observed in the hydrogen atom. This constant is closely associated with an electron's spin and orbital angular momentum, as described in Bohr's atomic model. Arnold Sommerfeld later extended Bohr's model by introducing relativistic corrections and elliptical orbits, using α to account for the fine structure observed in hydrogen's spectral lines [9,10]. Additionally, α plays a crucial role in determining the strength of the electromagnetic interaction between elementary charged particles. The fine-structure constant, α, is defined as follows:

$$\alpha = e^2 / 4\pi\varepsilon_0\hbar c \tag{1.1}$$

where e is the electron charge, ε_0 is the permittivity of free space, $\hbar$ is the reduced Planck constant, and c is the speed of light in a vacuum (approximately 3×10^8 m/s). From equation (1.1), we see that the term $1/4\pi\varepsilon_0$ is Coulomb's constant. Thus, we can rewrite equation (1.1) as:

$$\alpha = 2\pi k_e e^2 / hc \tag{1.2}$$

where h is Planck's constant, which is approximately 6.626×10^{-34} J·s, and k_e is approximately 8.99×10^9 N·m²/C². In certain contexts, k_e can also be expressed in terms of the electron's mass and classical radius [11] as follows:

$$k_e = m_e r_e c^2 / e^2 \tag{1.3}$$

where m_e and r_e are the electron's rest mass and classical radius which are equal to 9.1×10^{-31} kg and 2.82×10^{-15} meters, respectively. Similarly, Planck's constant can be expressed in terms of Planck's mass and length [12,13]:

$$h = 2\pi m_p l_p c \tag{1.4}$$

where m_p and l_p are Planck's mass and length, valued at 2.176×10^{-8} kg and 1.616×10^{-35} meters, respectively. Using equations (1.2) – (1.4), we can express the fine-structure constant in terms of:

$$\alpha = m_e r_e / m_p l_p \tag{1.5}$$

In 1924, Louis de Broglie proposed the concept of matter waves in his doctoral thesis. This idea, suggesting that elementary particles like electrons exhibit wave-like properties [14], became a

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foundational aspect of quantum mechanics. The relativistic energy from a matter wave can be expressed by the equation:

$$E = \frac{m_e c^2}{\sqrt{1-\left(\frac{v}{c}\right)^2}} = \gamma m_e c^2 = hf \tag{1.6}$$

where γ is the Lorentz factor and f is the frequency of the matter wave. From equation (1.6), we find that

$$\gamma = \frac{hf}{m_e c^2} = \frac{hc / \lambda_e}{m_e c^2} \tag{1.7}$$

where λ_e is the wavelength of the electron's matter wave. This wavelength can be determined as twice the radius of an electron, as described in a Nobel Prize-winning chemistry study from 2023 [15]. Thus, equation (1.7) can be rewritten as:

$$\gamma = \frac{2\pi m_p l_p c}{2 m_e r_e c} = \frac{\pi m_p l_p}{m_e r_e} \tag{1.8}.$$

Considering the equations (1.5) and (1.8), we can express the relationship of the fine-structure constant as:

$$\frac{\pi}{\gamma} = \frac{m_e r_e}{m_p l_p} = \alpha \tag{1.9}$$

we know that α is approximately 1/137. Then, γ is equal to

$$\gamma = \frac{\pi}{\alpha} \approx 430 \tag{1.10}.$$

Examining equation (1.10) shows that a free electron has a rotational velocity corresponding to a γ factor of approximately 430. With this rotational speed, the electron's velocity reaches 0.9999973c, which is nearly the speed of light. Notably, α is a dimensionless quantity, representing the ratio of π to γ, both of which are also dimensionless.

3. The Electron Anomalous Magnetic Moment and the π/γ Ratio

The fine-structure constant, α, and the anomalous magnetic moment of the electron are fundamental to understanding the behavior of charged particles, the strength of their interactions, and achieving precision measurements in quantum electrodynamics (QED). The anomalous magnetic moment, a_e, represents the deviation of the electron's actual magnetic moment from the value predicted by Dirac theory, which accounts only for basic relativistic effects and spin interactions. In Dirac's theory, the electron's magnetic moment is given by

$$\mu_e = g \cdot \frac{e\hbar}{2m_e} \tag{1.11},$$

where g is the electron's gyromagnetic ratio, also known as the g-factor, which is theoretically set to 2 [16–18]. However, due to higher-order QED effects, the experimentally measured g-factor deviates slightly from 2. This deviation results from interactions between the electron and the quantized electromagnetic field, which can be understood as exchanges of virtual photons and electron-positron pairs. The theoretical prediction for the anomalous magnetic moment involves an infinite series of QED corrections, expressed as:

$$a_e = \frac{g-2}{2} = \frac{\alpha}{2\pi} + \text{higher - order terms} \tag{1.12},$$

Although Dirac's theory sets g = 2, Schwinger's calculations of QED corrections introduced a first-order correction term of $\alpha/2\pi$, which matches experimental measurements to a high degree of precision [19]. By examining equations (1.10) and (1.12), we can express the leading-order correction term $\alpha/2\pi$ in terms of π/γ, finding:

$$\frac{\alpha}{2\pi} = \frac{\pi}{\gamma \times 2\pi} = \frac{1}{2\gamma} \tag{1.13},$$

which is approximately 1/860 or about 0.00116. This relationship underscores that both the fine structure constant and the anomalous magnetic moment arise from interactions between electrons and the quantized electromagnetic field, with both phenomena closely related to γ, a dimensionless constant critical for QED precision predictions.

4. Conclusions

This study explores a novel approach to understanding the fine-structure constant, α, by examining its connection to the anomalous magnetic moment of the electron through the ratio π/γ. Our findings indicate that α, a fundamental constant influencing the strength of electromagnetic interactions, can be interpreted as a simple ratio involving π and a relativistic Lorentz factor, γ. This ratio aligns with the electron's relativistic spin dynamics, providing insights into the electron's rotational behavior at velocities near the speed of light.

The anomalous magnetic moment, arising from electron spin interactions and deviations in the electron's magnetic moment from Dirac theory, is a central aspect of quantum electrodynamics corrections. By connecting α to π/γ, our approach suggests that both the fine-structure constant and the anomalous magnetic moment share a deep-rooted relationship influenced by relativistic and quantum corrections to electron dynamics. Specifically, the factor $\gamma \approx 430$ corresponds to an electron velocity approaching 0.9999973c, emphasizing the near-light speed rotational effects contributing to the values of both α and the magnetic moment anomaly.

In this framework, α emerges not only as a dimensionless constant but as an expression of the electron's relativistically corrected rotational dynamics, framed within the π/γ ratio. This proposition offers a unified perspective that links quantum mechanics, relativistic effects, and fundamental constants, providing a potential pathway toward a deeper understanding of the values and origins of constants that shape our physical theories. Future research could further investigate this relationship and its implications for bridging gaps between QED, relativity, and the foundational principles governing charged particle interactions.

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