Uncovering a New Physical Interpretation of the Fine-structure Constant

Tong Wang

Abstract

The fine-structure constant is an important dimensionless constant in physics. Several well-known physical interpretations of this phenomenon have been presented. In this study, we propose a new physical interpretation that connects the elementary charge and the Planck mass.

Keywords: Fine-structure Constant; Elementary Charge; Planck Mass

1. Introduction

The fine-structure constant [1], commonly denoted by α (the Greek letter alpha), is a fundamental physical constant.

α is a dimensionless quantity and is defined as follows:

$$\alpha = \frac{e^2}{4\pi \varepsilon_0 \hbar c}, \tag{1}$$

where e is the elementary charge, ε_0 is the vacuum permittivity, $\hbar$ is the reduced Planck constant, and c is the speed of light.

Historically, the numeric value of the reciprocal of α has often been given [2]

$$1/\alpha = 137.035999177(21) \tag{2}$$

One early physical interpretation of α was the ratio of the velocity of the electron in the first circular orbit of the relativistic Bohr atom to the speed of light in vacuum. Later, several additional physical interpretations of α were proposed. For instance, α is related to the coupling constant, which determines the strength of the interaction between electrons and photons.

In this study, we present a new physical interpretation that connects the relative magnitude of the gravitational potential energy between Planck masses and the magnitude of the electromagnetic potential energy between elementary charges.

2. Methods

Let us compare the gravitational potential energy between Planck masses with the electromagnetic potential energy between elementary charges with the same spatial separation.

First, by definition, the Planck mass [3], denoted by m_p here, is

$$m_p = \sqrt{\frac{\hbar c}{G}}, \tag{3}$$

where G is the gravitational constant. Therefore, the magnitude of the gravitational potential energy (U_p) between two Planck masses is

$$|U_p| = G\frac{m_p.m_p}{r}, \tag{4}$$

where r is the spatial distance between the two Planck masses.

Plugging equation (3) into equation (4), we have

$$|U_p| = G\frac{\hbar c}{Gr} = \frac{\hbar c}{r}. \tag{5}$$

Next, the magnitude of the electromagnetic potential energy (U_e) between two elementary charges is

$$|U_e| = \frac{e.e}{4\pi\varepsilon_0 r}, \tag{6}$$

where r has the same value as that in equation (4).

We calculated the magnitude of the gravitational potential energy between Planck masses and the magnitude of the electromagnetic potential energy between elementary charges, separated by the same distance. Now, let us compare their relative magnitudes (the ratio of them) by dividing equation (6) by equation (5).

$$\frac{|U_e|}{|U_p|} = \frac{\frac{e.e}{4\pi\varepsilon_0 r}}{\frac{\hbar c}{r}} = \frac{e^2}{4\pi\varepsilon_0 \hbar c}\,. \tag{7}$$

Plugging equation (1) into equation (7), we have

$$\frac{|U_e|}{|U_p|} = \alpha. \tag{8}$$

3. Results

From equation (8), we conclude that the ratio of the relative magnitude of the electromagnetic potential energy between elementary charges to the magnitude of the gravitational potential energy between Planck masses is α. Therefore, a new physical interpretation of the fine-structure constant is established.

4. Discussion

In this study, we calculate the relative magnitude of the electromagnetic potential energy between elementary charges and the gravitational potential energy between Planck masses. We find that the ratio is the fine-structure constant. It is also true that the ratio of the relative strength of the electromagnetic interaction between elementary charges to the strength of the gravitational interaction between Planck masses is the fine-structure constant.

The elementary charge and Planck mass are essential quantities that play many roles in physics. Through the fine-structure constant, we establish a connection between them. It is worth pursuing this direction further to find a deeper relationship between them. Moreover, a new physical interpretation of the fine-structure constant is uncovered.

Declarations

Funding statement

The authors did not receive support from any organization for the submitted work.

Conflicts of interest statement

The authors have no relevant financial or non-financial interests to disclose.

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author contribution statement

All the authors contributed to the study conception and design.

References

1. Sommerfeld, A.: Zur Quantentheorie der Spektrallinien. *Annalen der Physik*. **51,** 1-94 (1916).

2. NIST: "2022 CODATA Value: inverse fine-structure constant". *The NIST Reference on Constants, Units, and Uncertainty*. May (2024).

3. Planck, M.: Über irreversible Strahlungsvorgänge. *Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften zu Berlin*. **5,** 440–480 (1899).