the general science journal

Fine Structure Constant as the Polarization of the Quantum Field by a Unit Charge

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Since it was first discovered, physicists have attempted to find the fundamental physical cause of the fine structure constant. The fine structure constant appears in many different physics relationships and can be expressed in terms of a number of combinations of different physical constants. This leads to some debate over what is the most fundamental representation of the constant. In this paper it is first shown that the unit charge can be viewed as the polarizability of space over a surface area surrounding a unit charge. The polarizability of space is in turn determined by the van der Waals torque of the quantum field. That torque regulates the rate of rotation of the quantum dipoles of standard model quantum field theory as each quantum dipole is polarized. Then, based on the well-known relationship between the charge squared and the fine structure constant, it can be readily shown that the fine structure constant is the total volumetric polarization of the quantum field due to a single unit charge. This shows that the fine structure constant can be fundamentally derived as an effect due to fundamental electrodynamics of the quantum field.

1. Introduction

Ever since the fine structure constant was first introduced by Sommerfeld, physicists have questioned what it physically represents and if it can be derived from more fundamental principles. The fine structure turns up in many relationships that can be expressed in terms of other well-known physical constants such as those shown in Equation 1 where the fine structure constant ($\boldsymbol{\alpha}$), is given as a function of electric charge ($\boldsymbol{e}$), the reduced Planck's constant ($\boldsymbol{\hbar}$), the speed of light ($\boldsymbol{c}$), and the permittivity of space ($\boldsymbol{\varepsilon_0}$).

Equation 1

$$\alpha = \frac{1}{4\pi\epsilon_0}\frac{e^2}{\hbar c}$$

While physicists have contemplated whether one occurrence of the fine structure constant is more fundamentally than other occurrences, there is no consensus as to which is more fundamental. So far, none of the occurrences of the fine structure constant appear to be a fundamental derivation of the constant based on something more fundamental than the standard physical constants.

In this paper it will be shown that the fine structure constant can be derived as the volumetric polarization of the quantum field due to a unit charge.

2. The Quantum Field

In standard model quantum field theory space contains a sea of virtual matter-antimatter particle pairs. These particle pairs are normally treated as Dirac-Fermions such as electron-positron pairs but may conceivably be any truly fundamental matter-antimatter pair of particles. Particle pairs with non-zero electric charge form electric dipoles. However, virtual photons behave like dipoles due to their rotating electric and magnetic fields.

In the quantum field of electric charge dipoles, they necessarily undergo van der Waals interactions. The van der Waals interactions lead to van der Waals forces, notable those forces cause the Casimir effect which has been experimentally verified.[1][2][3] The two-plate example was the first example considered by Casimir in which two plates are pushed together by van der Waals forces. He showed that two plates are pushed together by van der Waals forces of the quantum field when the plates are close together.

The existence of the dipoles of the quantum field gives us a physical explanation of how electromagnetic interactions occur in space. As Dicke said "The most striking effect of the presence of virtual pairs in the vacuum is the polarizability of the vacuum." And, "With the neglect of quantum effects the polarizability of the vacuum can be described by classical field quantities $\boldsymbol{\varepsilon}$ and $\boldsymbol{\mu}$." [4] A charge in space causes the quantum dipoles to be polarized and a moving charge causes those dipoles to rotate as shown if Fig. 1.

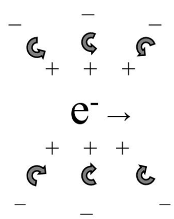

Fig. 1. As an electron moves through space nearby quantum dipoles are polarized and rotate.

Another van der Waals interaction necessarily arises within a sea of quantum dipoles. This interaction is van der Waals torque. Quantum dipoles have inertia, so they resist rotation, and yet, whenever a charge appears in space, quantum dipoles must rotate and become polarized. And whenever a charge moves, quantum dipoles must rotate. The resistance to rotation is the van der Waals torque. The van der Waals torque of the quantum field resists polarization of the quantum dipoles during propagation of both electric and magnetic fields.

3. Electric Charge

To understand the fine structure constant, we must first understand the fundamental nature of electric charge. From Gauss' Law a volume of space is polarized by the electric charge within that volume. This can be expressed as shown in Equation 2 as the surface integral of the flux of the polarization (**P**) over the surface area **A.**

Equation 2

$$Q = \oint_S P \cdot dA$$

To comply with the principle of conservation of energy and the inverse square law, the total flux over the area of any radius sphere will be the same. Gauss' law for a single unit of charge gives us Equation 3, which tells us that a unit charge is directly related to the polarizability of the quantum field, which we now know is determined by the van der Waals torque of the quantum field.

Equation 3

$$e = \oint_S P \cdot dA$$

This gives us a chicken and egg type problem. Which is more fundamental, electric charge or the polarizability of the quantum field? Historically the quantum field has been ignored by renormalizing and setting the properties of space equal to the permittivity, permeability, and other constants.

In the case where quantum field effects are ignored, physicists treat electric charge as a fundamental property. In the case where we consider quantum field effects, such as van der Waals torque, the polarizability of space is more fundamental.

To determine which view is correct we must consider particles. Particles have different masses and different hypothetical sizes and structures and yet somehow, they always have the same unit charge or multiples of the unit charge including zero charge. It has always been a mystery as to how this can happen as we have no way to physically account for it. And yes, there are theoretical fractionally charged particles, but they do not appear in a free state and as such, we do not see fractional polarization of the quantum field emanating from particles.

Alternatively, we can consider that the polarizability of space due to a single polarizer must be the same for any polarizer. Given this approach it is much easier to understand how we can arrive at a standard unit charge for numerous types of particles. It is the polarizability of space that remains constant while each particle acts as a unit polarizer. It is fundamentally better to think of a unit charge as a unit polarizer, which gives us the answer to our chicken and egg problem.

A unit electric charge is due to the polarizability of space due to a single polarizer—particle. The polarizability of the quantum field is determined by the van der Waals torque of the quantum field.

4. The Fine Structure Constant

To get a better understanding of the fundamental nature of the fine structure constant we can modify Equation 1 by putting it in terms of a set of natural units where $\boldsymbol{\varepsilon_0}$, $\boldsymbol{c}$, and $\boldsymbol{\hbar}$ are set to one in dimensionless units. That gives us Equation 4, which gives us the well-known fundamental relationship between the fine structure constant and electric charge.

Equation 4

$$\alpha = \frac{e^2}{4\pi}$$

We can also put Equation 1 in terms of $\boldsymbol{h}$ and set $\boldsymbol{h}$ to 1 in another set of natural units. This gives us a slightly simpler relationship between the fine structure constant and electric charge as shown in Equation 5. Using either Equation 4 or 5 we can determine the value of $\boldsymbol{e}$ in either set of natural units based on the known value of $\boldsymbol{\alpha}$. The difference between the two equations is that one is useful for problems expressed in circular or spherical geometry and the other can be used more generally.

Equation 5

$$\alpha = \frac{e^2}{2}$$

We must note that these equations tell us that because $\boldsymbol{\alpha}$ is related to $\boldsymbol{e}$, which is known to be due to the polarizability and van der Waals torque of the quantum field, then the fine structure constant must also be due to the polarizability and van der Waals torque of the quantum field.

To understand how, we must consider the question of what it means physically for $\boldsymbol{\alpha}$ to be proportional to $\boldsymbol{e}^2$. More basically we can ask what is the physical interpretation of $\boldsymbol{e}^2$? Equation 3 tells us that $\boldsymbol{e}$ is the polarization of space for a single polarizer. This is where physicists have been stuck, looking at Equation 4 and less commonly Equation 5 and pondering their meaning.

We can see a possible path forward by recognizing that the right-hand part of Equation 4 is in the form of the result of the simple integration of x shown in Equation 6.

Equation 6

$$\int x\, dx = \frac{x^2}{2}$$

If we go back to Equation 3 for charge we see that we can derive the $\boldsymbol{e^2/2}$ term by integrating $\boldsymbol{e}$. To simplify the integration, we can consider just the spherical surfaces integrated over a range of radii from 0 to infinity. This is shown in Equation 7 with the term for the unit charge ($\boldsymbol{e}$) from Equation 3 inside the parentheses.

Equation 7

$$\int_0^{\infty} \left(\oint_S P \cdot dA \right) dr = \frac{e^2}{2}$$

A unit of electric charge is the polarizability of space over a surface area surrounding a unit polarizer—charge. By taking a second integral we are no longer considering the polarization of an area, but rather the polarization throughout the volume of space.

We can conclude that the fine structure constant is the polarization of the total volume of space due to a unit polarizer—charge. This was calculated in natural units with $\boldsymbol{\varepsilon_0}$, $\boldsymbol{c}$, and $\boldsymbol{\hbar}$ set to 1 in order to simplify the terms, but it can be calculated in any set of units. The fine structure constant is due to the polarizability of the quantum field which is determined by the van der Waals torque of the quantum field.

5. Conclusion

By first acknowledging the proven existence of the quantum field of standard model quantum field theory, we can recognize that the polarizability of space expressed in Gauss' law is due to the physical polarization of quantum dipoles. This tells us that electric charge is due to the polarizability of physical quantum dipoles. Because a field of quantum dipoles must additionally exhibit van der Waals torque, the van der Waals torque of the quantum field determines the polarizability of space.

Further we can see that the uniformity of polarization effects within the quantum field gives us a better explanation for the existence of the unit charge emanating from different particles with different physical characteristics. It is better to think of the quantum field as the underlying reason for unit charge, as the polarization of the quantum field is uniform for any polarizer—particle.

Given the well-known relationship between the square of the electric charge and the fine structure we can examine what that physically means. It is simple to show that the electric charge squared term can be achieved through a simple integration of electric charge over the volume of space.

This tells us the relationship between electric charge and the fine structure constant. While the unit electric charge is the polarization on a surface surrounding a unit polarizer—charge—, the fine structure constant is the total polarization of space due to a unit polarizer—charge.

In answer to the original two questions the fine structure constant can be derived from and its physical origin explained as a property of the polarizability and van der Waals torque of the quantum field.

References

[1] Casimir, H.B.G., and Polder, D., (1948) "The Influence of Retardation on the London-van der Waals Forces," Phys. Rev. 73, 360-372.

[2] Lamoreaux, S. K. (1997), "Demonstration of the Casimir Force in the 0.6 to 6 μm Range". Physical Review Letters 78: 5. doi:10.1103/PhysRevLett.78.5.

[3] Mohideen, U.; Roy, Anushree (1998), "Precision Measurement of the Casimir Force from 0.1 to 0.9 μm". Physical Review Letters 81 (21): 4549. doi:10.1103/PhysRevLett.81.4549.

[4] Dicke, R.H., (1957), "Gravitation without a Principle of Equivalence," Rev. Mod. Phys., 29 363.