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The “Holy” Particle

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Abstract

A revised theoretical treatment of Sommerfeld’s fine-structure constant is discussed. This treatment takes into consideration our Universe’s acceleration on the energy interaction between particles. The analysis is further refined to account for relativistic speeds that are more typical during such interactions. This treatment postulates the existence of the “Holy” particle.

INTRODUCTION

In the early days of developing Quantum Mechanics, scientists made significant strides in understanding the universe around us. One such contribution is attributed to Arnold Sommerfeld in his development of the fine-structure constant, which offered us a new understanding of energy coupling between interacting particles. While revolutionary, Sommerfeld’s treatment did not consider the effects of cosmological expansion and acceleration. In light of recent evidence, confirming the relativistic expansion of our universe, an updated theoretical treatment is appropriate for a “closer-to-reality” understanding of Nature. New insights are revealed during this refinement process that postulate the existence of a new particle which poses more questions and potentially new methodologies for better understanding of mediation of forces in Nature.

THE PLANCK CONSTANT

Max Planck agonized over the “ultraviolet catastrophe”, a term coined by Paul Ehrenfest in 1911. Also known as the Rayleigh-Jeans catastrophe, it was a prediction of early 20th century classical physics that an ideal black body will emit an infinite amount of energy in the form of electromagnetic radiation as shown in Figure 1.

In addressing the contradiction between the experimentally observed finiteness of energy and the Rayleigh-Jeans prediction of infinite energy, Planck recognized the catastrophic prediction arose due to a classical assumption that energy was a continuous variable. Consequently, Planck modified the mathematical tools of classical physics to accept energy as discontinuous, discrete or quantized. He demonstrated that every “energy element” must be proportional to the frequency of an atom’s oscillating mode. When an atom vibrates it does so at specific quantized frequencies and every frequency is a measure of the atoms energy. The “Planck’s relation” is the mathematical description of this energy property:

$$E = \hbar\omega$$

Where E represents the energy element, $\hbar$ is the reduced Planck constant and ω is the angular frequency of an atom’s oscillating mode.

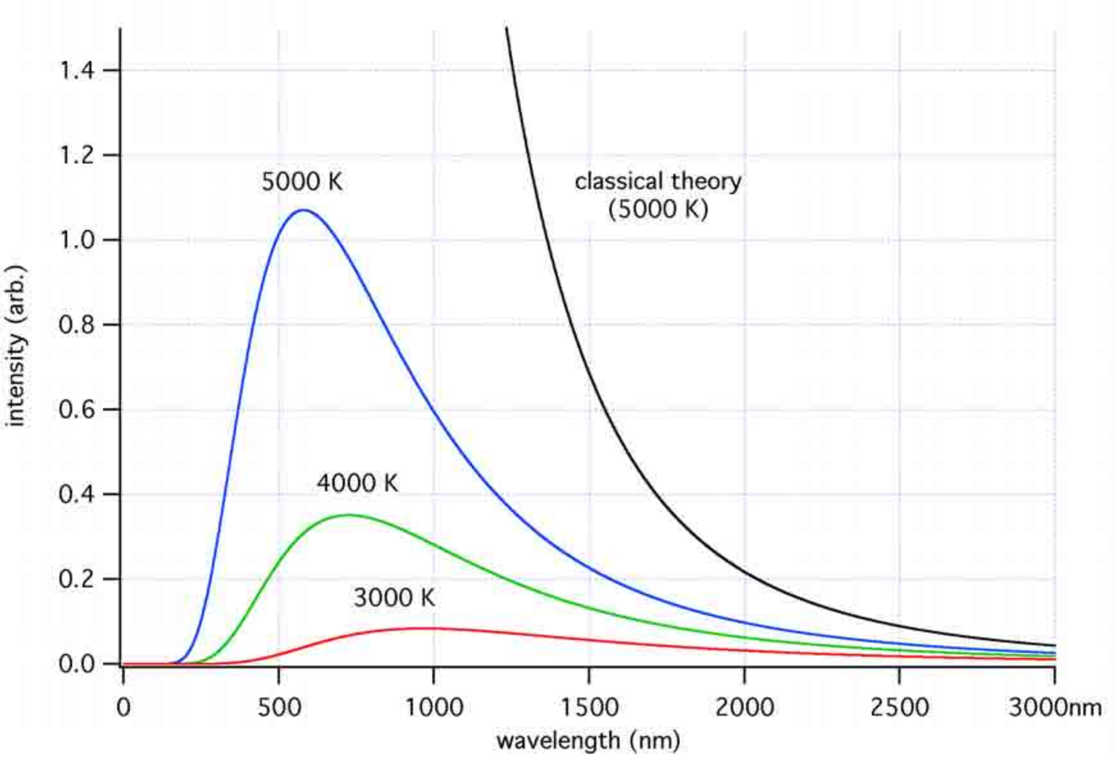

Figure 1. The Rayleigh-Jeans black body catastrophe

In 1911, Planck unveiled his theory at the first Solvay Conference, a gathering of preeminent contemporary physicists, and presented his model's more realistic prediction of black body radiation, as shown in Figure 2, *i.e.* objects in nature do not continuously emit infinite energy. In 1918, Planck received the Nobel Prize in Physics in recognition of his contributions to the advancement of physics by his discovery of energy quanta. Quantum Mechanics was born and Planck had laid the foundations of post-classical physics.

The Plank constant $\hbar$ is an atomic scale constant whose value is often quoted as $6.58211899 \times 10^{-16}$ eVs. It defines the smallest possible physical dimension in the universe and describes the gap between fundamental energy discontinuities. In other terms, nature is digital: in superbly high definition, maybe, but still digital.

HEISENBERG'S UNCERTAINTY PRINCIPLE

The analog-to-digital conversion of our Universe by Planck implies an inherent uncertainty in nature. Heisenberg was the first to articulate nature's uncertainty in a principle that carries his name. His 1927 paper described the following uncertainty formulation:

$$\Delta x \Delta p \approx \hbar$$

Where Δx represents the uncertainty in the spatial dimension and Δp represents the uncertainty in momentum space.

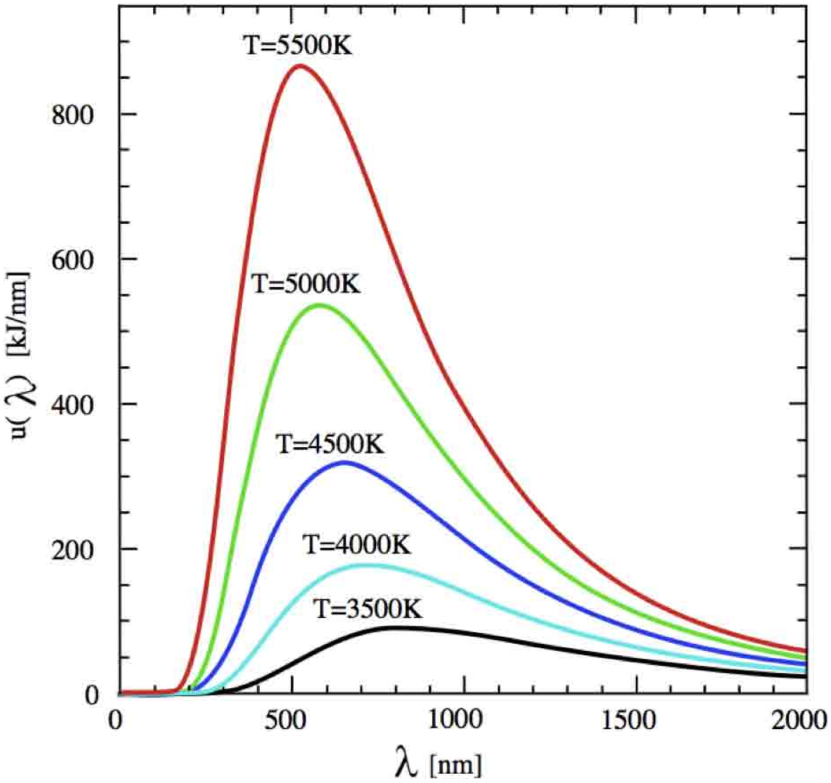

Figure 2. Planck's more accurate black body radiation predictions

To illustrate, if the uncertainty in position of an object is small ($\Delta x \rightarrow 0$), the uncertainty of momentum in the same direction necessarily grows ($\Delta p \rightarrow \infty$) to a size that ensures the product of Δx and Δp remains in the order of $\hbar$.

From a philosophical perspective, nature affords all existing objects some level of freedom, or free will, and determinism had fallen out of favor. It is not possible to predict any observable with absolute accuracy. It was in protest to the fall of determinism and the subsequent emergence of logical positivism over realism that led to the popularization of the quote: "God does not play dice," attributable to Einstein.

SOMMERFELD'S FINE-STRUCTURE CONSTANT

Further developments in Quantum Mechanics led Arnold Sommerfeld to study the strength of energy interactions between particles and through which he formulated his fine-structure constant, usually denoted as α, in 1916. α is a fundamental physical constant, also known as a coupling constant, that characterizes the strength of the electromagnetic interaction, or coupling, between particles. A dimensionless quantity, it is represented as follows:

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

Where e is the electronic charge, c is the speed of light in vacuum and ε_o is the permittivity of free space. In electromagnetics, ε_o is often defined as the extent to which electrical lines of flux are concentrated.

Physical interpretations of Sommerfeld's fine-structure constant are abundant. Among the most controversial are those that invoke the anthropic principle: α exists since stable matter exists and, therefore, life and intelligence exist. Were α to be any different, stellar fusion would not produce carbon of which we are made. Conversely, if stellar fusion were not possible, no place in the universe would be warm enough for life. Thus, according to the anthropic principle, were it not for Planck's constant, life as we know it would not exist; take away free will, and life ceases to exist.

THEORETICAL TREATMENT

EINSTEIN'S COSMOLOGICAL CONSTANT

Sommerfeld's equation for the fine-structure constant has survived unchanged almost a century. There was little reason to re-evaluate it, up until now. In light of cosmic acceleration, a revised treatment of Sommerfeld's work is appropriate.

In his formulation of General Relativity, Einstein, rather arbitrarily, introduced the cosmological constant into his equations, usually denoted as λ, to ensure the results always achieve a stationary and stable universe. At the time, around 1917, the view of a static universe was considered more intuitive than cosmological expansion or contraction. Without this cosmological constant, Einstein's general relativity equations predicted that gravity would cause a universe to contract.

However, by 1929, Edwin Hubble and Milton Humason confirmed that our universe is expanding. Faced with this experimental observation, Einstein abandoned his cosmological constant and called it the "biggest blunder" of his life.

The scientific community today views the cosmological constant more subtly and credits Einstein with considerable foresight. Contrary to earlier solutions to Einstein's general relativity equations, adding the cosmological constant is not thought to lead to a static universe at equilibrium because the equilibrium itself is unstable. To illustrate, consider a slight perturbation around the equilibrium, such as a slight expansion of the universe. Such a small expansion releases vacuum energy, which causes yet more expansion, *ad infinitum*, in an accelerating or inflationary fashion, revealing the instability of the equilibrium. This is consistent with experimental observations, which recently confirmed that our universe is not only expanding but doing so in an accelerating manner. Einstein's cosmological constant is therefore necessary in accounting for cosmic acceleration.

In Sommerfeld's work on the fine-structure constant, no consideration was provided for cosmic acceleration. The assumption had been that the universe was static and in stable equilibrium. A more accurate theoretical treatment of the strength of interaction or coupling of energy between particles would account for experimental observations that confirm the universe's acceleration. This is accomplished by reformulating the fine-structure constant a follows:

$$\alpha_c = \lambda\alpha = \frac{\lambda e^2}{\hbar c 4\pi\varepsilon_o}$$

Where the cosmological constant, λ, has been incorporated into the equation. The resultant constant is represented by α_c. The *c* subscript here indicates that the fine-structure constant, α, has been modified to account for cosmic acceleration. Also, α_c is no longer dimensionless. It takes on the dimensions of the cosmological constant: energy density.

THE LORENTZ TRANSFORMATION

Certain contemporary theories of cosmic expansion predict that the universe is expanding at speeds that approach the speed of light. Conservative estimates of this expansion reveal speeds in the order of 4.5×10^7 m/s (or 45 thousand kilometers per second). Comparatively, speed of light *in vacuo* is 3×10^8 m/s (300 thousand kilometers per second). Such conservative estimates, indicate that our universe is currently expanding close to 15% of the speed of light, typically denoted as $0.15c$. It is generally accepted that relativistic effects begin to dominate around $0.1c$.

Considering that cosmic acceleration is occurring at relativistic speeds, α_c, Sommerfeld's fine-structure constant modified to account for cosmic acceleration, can be further refined. The Lorentz factor, generally denoted as γ, and named after the Dutch physicist Hendrik Lorentz is typically invoked as the mathematical tool used to account for relativistic effects. The Lorentz factor is a dimensionless quantity defined as:

$$\gamma = \frac{c}{\sqrt{c^2 - u^2}}$$

Where u is the velocity of an object or particle in the reference frame where time is measured.

The Lorentz equation above indicates that if a particle's velocity is non-relativistic or close to stationary ($u \to 0$), γ takes on the value of one. However, if the velocity approaches the speed of light ($u \to c$), γ takes on an infinite value ($\gamma \to \infty$) since the denominator approaches zero.

In his formulation of the theory of special relativity, Einstein relied heavily on the Lorentz transform, to eventually produce his well-known Energy-Mass relationship:

$$E = mc^2$$

Where E is the total energy available in an object of mass m. However, this popularized version of Einstein's energy equation is an approximation. His actual energy equation is:

$$E = \gamma mc^2$$

Where γ is the same Lorentz factor described above. In popular culture, Einstein's equation is discussed in relation to non-relativistic objects, where γ is essentially unity. Once the moving objects are in the relativistic realm, γ cannot be approximated as 1, and continues to grow with the velocity of the object. Indeed, as the velocity approaches the speed of light, γ approaches infinity as discussed. This is consistent with Einstein's theory of special relativity, which suggests bringing an object to travel at the speed of light would require infinite energy. Hence, according to special relativity, the speed of light is a natural physical limit.

Using the Lorentz transform to account for the relativistic speeds of cosmic acceleration, the fine-structure constant is modified as follows:

$$\alpha_{rc} = \lambda\gamma\alpha = \frac{\lambda\gamma e^2}{\hbar c 4\pi\varepsilon_o}$$

Where the Lorentz factor, γ, has been incorporated in a consistent manner to Einstein's energy-mass relationship, α_{rc} is the new fine-structure constant corrected for relativistic cosmological effects. Like α_c, α_{rc} is not dimensionless. It maintains the dimensions of the cosmological constant (energy density) since γ is dimensionless.

A NEW PARTICLE

The above equation for α_{rc} warrants further analysis. α_{rc} is divided into a numerator ($\lambda\gamma e^2$) and a denominator ($\hbar c 4\pi\varepsilon_o$). Planck's constant, $\hbar$, and the permittivity of free space, ε_o, are in the denominator. As an aside, the denominator, $\hbar c 4\pi\varepsilon_o$, is well known in the field as the square of the Planck charge, q_p:

$$q_p = \sqrt{\hbar c 4\pi\varepsilon_o}$$

The product of the Planck constant and the permittivity of free space, $\hbar\varepsilon_o$, can be moved to the left hand side of the above equation for α_{rc} by multiplying both sides by $\hbar\varepsilon_o$. This is illustrated below:

$$\hbar\varepsilon_o\alpha_{rc} = \hbar\varepsilon_o\lambda\gamma\alpha = \frac{\hbar\varepsilon_o\lambda\gamma e^2}{\hbar c 4\pi\varepsilon_o}$$

Which, after the cancellations, reduces to:

$$\hbar\varepsilon_o\alpha_{rc} = \hbar\varepsilon_o\lambda\gamma\alpha = \frac{\lambda\gamma e^2}{c 4\pi}$$

The left hand side of the above equation represents the corrected fine-structure constant, α_{rc}, multiplied by the product $\hbar\varepsilon_o$. This can be replaced with α_m, to mean the *modified fine-structure constant* and this further simplification produces the following:

$$\alpha_m = \hbar\varepsilon_o\lambda\gamma\alpha = \frac{\lambda\gamma e^2}{c4\pi}$$

The right hand side of the equation confirms the dimensional correctness of the theoretical treatment and also explains the physical significance of α_m, both of which will be discussed below. Focusing on the definition of α_m, the equation for the modified fine-structure constant can be reproduced as follows:

$$\alpha_m = \hbar\varepsilon_o\lambda\gamma\alpha$$

Based on the dimensional analysis, the $\hbar\varepsilon_o\lambda\gamma\alpha$ constant carries the following units:

$$\frac{[Mass]\times[Ch\arg e]^2}{[Dis\tan ce]^2\times[Time]}$$

Upon close inspection of the units above, the $\hbar\varepsilon_o\lambda\gamma\alpha$ constant is not merely a constant. It describes an exponentially charged mass that is perceived depending on its spatial separation from an interacting entity as well as on the duration of such interaction. An exponentially charged mass with such interaction properties leads to the postulate of the existence of a new particle: the $\hbar\varepsilon_o\lambda\gamma\alpha$, or "Holy", particle.

INTERPRETATON AND CONCLUSIONS

Almost one century after Sommerfeld, a new formulation of his fine-structure constant is presented that takes into consideration cosmological acceleration at relativistic speeds. This has led to a postulate of the existence of a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle. It is described by five fundamental physical constants:

$\hbar$	The Planck Constant: The smallest physical dimension in the universe describing the gap between energy discontinuities that necessarily result in the Heisenberg Uncertainty Principle
ε_o	Permittivity of Free Space: Measure of the extent to which it concentrates electrical lines of flux
λ	The Cosmological Constant: Necessary to account for cosmic acceleration
γ	The Lorentz Factor: Necessary to adjust for relativistic speeds
α	The original Sommefeld fine-structure constant characterizing the strength of energy interactions

This is a particle that is electrically charged; exhibits unpredictability through exercising free will; it concentrates electrical lines of flux; it travels at relativistic speeds and cosmic accelerations; and it strongly interacts with objects .

It is also a curious particle in the sense that the way it interacts with others strongly depends on the proximity and duration of such interaction. From the units of $\hbar\varepsilon_o\lambda\gamma\alpha$, the particle is inversely proportional to the square of the separation as well as time. Consider an interacting entity always maintains the same distance from a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle. Over time, the strength of the interaction with a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle diminishes according to the inverse relationship.

Conversely, consider if time is stopped but the separation between a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle and an interacting entity is varied. As the separation grows, the strength of interactions approaches zero according to a square inverse relationship. Yet if the separation shrinks, the strength of interaction approaches infinity. The closer one is to a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle the stronger the coupling of energy.

In reality, it may thus appear that interactions with a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle must necessarily diminish over time. However, increasing the proximity to a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle over time would counter the diminishing effects of time. Indeed, since the strength of interactions is inversely proportional to the square of the separation, it is possible, for example, to maintain the strength of coupling by increasing proximity 10-fold, over a 100-fold increase in time. This is graphically represented in Figure 3.

It is hypothesized that a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle transmits energy through coupling with other particles. Such energy transfer diminishes over time unless the interacting particles continue to increase their proximity to a $\hbar\varepsilon_o\lambda\gamma\alpha$ particle in accordance with the inverse square relationship discussed above. This energy transfer mechanism may explain the process through which massless particles, such as photons, can acquire mass, becoming, for example, massive W or Z bosons. Furthermore, it is conjectured that the $\hbar\varepsilon_o\lambda\gamma\alpha$ particles interacts solely through a Higgs field. It is not suggested here that the $\hbar\varepsilon_o\lambda\gamma\alpha$ particle is the Higgs boson, popularized as the "God" particle by Leon Lederman, from which all massive particles are made. Instead, the $\hbar\varepsilon_o\lambda\gamma\alpha$ particle provides the mechanism of energy/mass transfer between a Higgs boson and other particles. As such, while not the "God" particle, it is appropriate to call it a "Holy" particle.

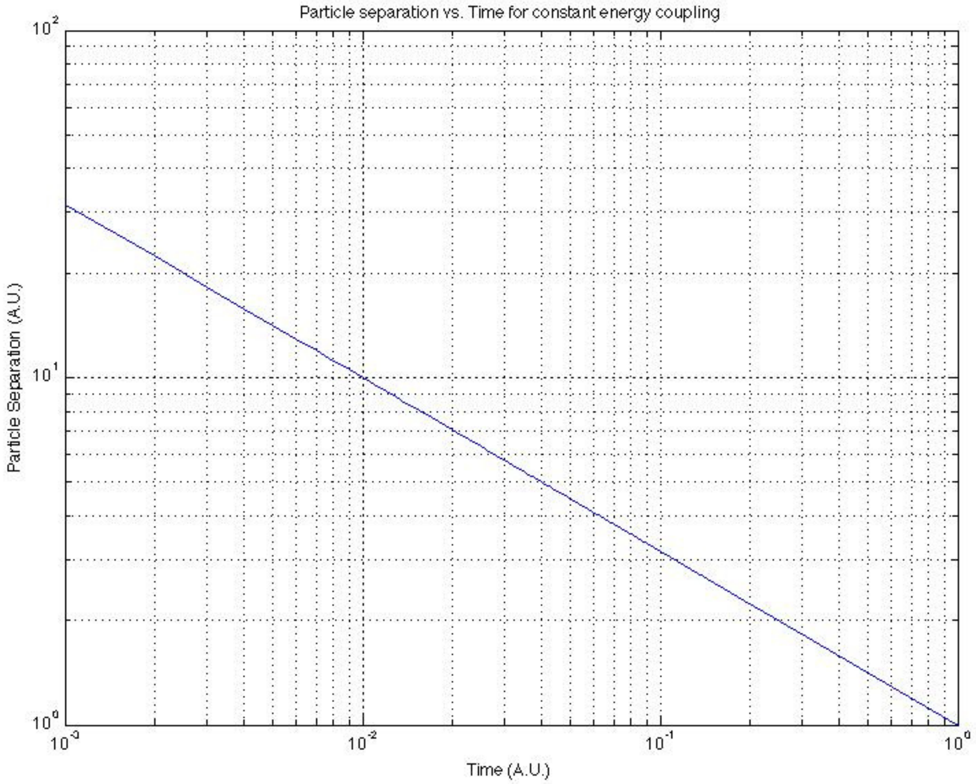

Figure 3: Particle Separation as a function of Time

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