Comments on the Quantum Vacuum and the Light Acceleration

Nosratollah Jafari and Ahmad Shariati

1 Institute for Advanced Studies in Basic Sciences, P.O. Box 159, Zanjan 45195, Iran
E-mail: njafary@iasbs.ac.ir

2 Department of Physics, Alzahra University, Tehran 19938-91167, Iran.
E-mail: shariati@mailaps.org

November 4, 2018

Abstract

The recent observations on the far quasars absorption lines spectra and comparison of these lines with laboratory ones provide a framework for explanation of these observations by considering a varying fine structure constant, over the cosmological time-scale. Also, there seems to be an anomalous acceleration in the Pioneer spacecraft 10/11 about $10^{-10}$ m/s$^2$. These matters lead Ranada to study the quantum vacuum to explain these problems by introducing a phenomenological model for the variation of $\alpha$.
In this manuscript we want to show that this model is not a quantum model; it is a classical model that is only in accordance with mentioned observations by adjusting some parameters and is not based on a fundamental physical intuition.

1 Introduction

The recent observations on the far quasars absorption lines spectra and comparison with laboratory spectra show that these quasars are dimmer than the nearer ones [1]. The Webb group try to explain these observations by considering a varying fine structure constant [2]. The variation of the fine structure constant $\alpha = e^2/4\pi\epsilon_0c$ leads to the variation of its constitutes i.e. the light speed $c$ or electron charge $e$ or Planck constant $\hbar$. The variation of the electron charge and the Planck constant is not so plausible [3]. Thus, there is no way except the variation of the light speed, if we accept the variation of the fine structure constant.
The Pioneer 10 and 11 spacecraft launched on 2 March 1972 and 5 April 1973 for studying the outer planets. When at 20 AU the solar radiation pressure acceleration had decreased to \(< 5 \times 10^{-10} \text{ m/s}^2\), the JPL’s Orbit Determination Program analysis of unmodelled acceleration found that between 20 AU and 70 AU the biggest systematic error in the acceleration residuals is a constant bias of

\[ a_p = (8.74 \pm 1.33) \times 10^{-10} \text{ m/s}^2, \]

directed toward the Sun within the accuracy of Pioneer antennae. This anomalous acceleration is addition to the acceleration exerted by the Sun and other objects in the Solar System in the frame of general relativity and has not attend a convenient explanation till now [4, 5].

Ranada introduce a phenomenological model based on the variation of the density of the virtual pairs created in the ground state of the quantum vacuum for the explanation of these matters [6, 7, 8].

In this manuscript, we summarize the Ranada’s approach in the next section and investigate his model and results in the third section.

2 The Ranada’s Approach

Quantum physics states that the sea of virtual pairs that are created and destroyed constantly in the quantum vacuum i.e. the zero-point energy state, has infinite density. If this density can be finite then according to Heisenberg’s fourth uncertainty relation (the Energy-Time relation) a virtual pair created with energy \( E \) (including rest-mass energy, kinetic energy and electromagnetic energy) will live during a time \( \tau_0 = \frac{\hbar}{E + E \Phi} \). In the gravitational potential \( \Phi \) the life time of this virtual pair increases to

\[ \tau_0 = \frac{\hbar}{E + E \Phi} = \frac{\tau_0}{1 + \Phi/c^2} \]

and the number density of pairs also increase to

\[ N_\phi = \frac{N_0}{1 + \Phi/c^2} \]

The increasing is due to the negativity of \( \Phi \) [9]. In this approach the quantum vacuum is treated as an ordinary transparent optical medium with permittivity and permeability that depends on \( \Phi \). If we write the permittivity and permeability as \( \varepsilon_r \varepsilon_0 \) and \( \mu_r \mu_0 \) (the \( \varepsilon_0 \) and \( \mu_0 \) are the permittivity and permeability of the vacuum in the Earth), then in case of the weak field, their dependence on the potential \( \Phi \) can be expressed as

\[ \varepsilon_r = 1 - \beta(\Phi - \Phi_E)/c^2 \]  
(1)

\[ \mu_r = 1 - \gamma(\Phi - \Phi_E)/c^2 \]  
(2)

In the above relation \( \Phi \) is the gravitational potential at the observation point and \( \Phi_E \) is the gravitational potential in the Earth, \( \beta \) and \( \gamma \) being certain coefficients and \( c \) is the present value of the light speed.

After some reasoning we reach to the following relation for the variation of light speed and the fine structure constant

\[ c(t) = c[1 + (\beta + \gamma)F(t)\Phi_0]/2c^2 \]  
(3)

\[ \alpha(t) = \alpha[1 + \xi F(t)\Phi_0]/2c^2. \]  
(4)
Thus, the value of the $\Delta \alpha/\alpha$ becomes $\xi F(t)\Phi_0/2c^2$. That is, $\xi = (3\beta - \gamma)/2$. Also, the light acceleration becomes $a_p = -H_0c(\beta + \gamma)(1 + 3\Omega_\Lambda)$. In the above relation $\Phi_0 \simeq -0.3c^2$ is the gravitational potential due to the critical density distributed up to the distance of $R_U \simeq 3000\text{Mpc}$ and $F(t)$ is

$$F(t) = \Omega_M \left[ \frac{1}{a(t)} - 1 \right] - 2\Omega_\Lambda [a^2(t) - 1]$$

in which $a(t)$ is the scale factor, $\Omega_M$ and $\Omega_\Lambda$ are the present-time relative density of matter (ordinary plus dark) and dark energy corresponding to the cosmological constant $\Lambda$.

By comparing the relation (4) by Webb’s result and the light acceleration $a_p$ with Pioneer acceleration yield $10^{-5}$ for the $\xi$ and 2 for the value of $(\beta + \gamma)$. Thus, by substituting these values for $\xi$ and $(\beta + \gamma)$ back in the relations (3) and (4) we obtain $10^{-5}$ for the $\Delta \alpha/\alpha$ and $10^{-8}$ m/s$^2$ for the Pioneer acceleration which coincide with the observations.

3 Investigating the Ranada’s Method and Results

The Ranada’s approach in contrast with his claim is not a quantum approach. The relations (1) and (2) are obtained from a phenomenological deductions based on the variation of the density of virtual pairs in quantum vacuum, but there is no dependency on $\hbar$ in these relations. It can be said that the $\beta$ and $\gamma$ coefficients depend on $\hbar$ implicitly and this dependency can be obtained from an ultimate quantum vacuum theory. (In present time we have not such a theory.) But, the very large value of $\beta$ and $\gamma$ with respect to $\hbar$, that are respectively 1.5 and 0.5, makes the quantum origin of these coefficients nearly impossible. On the other hand, $\beta$ and $\gamma$ coefficients are dimensionless constants, so they cannot depended on $\hbar$, unless we introduce some new dimensionful constants. (In the relation (1) and (2) the term $(\Phi - \Phi_E)$ is of the $c^2$ order. Thus, the order of magnitude of $\epsilon_r$ depends solely on the $\beta$ and also the same matter for $\mu_r$ and $\gamma$.)

In fact, the Ranada’s model is a model for coupling the electromagnetic and gravity. In this regards the most general Lagrangian has been studied by P. Teyssandier \cite{10} and I. T. Drummond \cite{11}

$$S = \int \left[ -\frac{c^3}{16\pi G} (R + 2\Lambda) + L_{EM} - j^\mu A_{\mu \nu} + L_{matter} \right] \sqrt{-g} d^4x$$

in which

$$L_{EM} = -\frac{1}{4} F_{\mu \nu} F^{\mu \nu} + \frac{1}{4} \xi R F_{\mu \nu} F^{\mu \nu} + \frac{1}{2} \eta R_{\mu \nu} F^{\mu \rho} F_{\rho \nu} + \frac{1}{4} \zeta R_{\mu \nu \rho \sigma} F^{\mu \nu} F^{\rho \sigma}$$

the $\xi$, $\eta$ and $\zeta$ constants are related to the fine structure constant and the electron Compton wavelength $\lambda_c = \hbar/m_e c$ as

$$\xi = -\frac{\alpha}{36\pi} \lambda_c^2 \ , \ \eta = \frac{13\alpha}{180\pi} \lambda_c^2 \ , \ \zeta = -\frac{\alpha}{90\pi} \lambda_c^2.$$
We can see that there is a difference between $c_l$, the light speed in this Lagrangian, and $c$, the usual light speed\[10\], but this difference is very tiny

$$\frac{c_l}{c} \sim 1 + 10^{-81}.$$  

This is very small relative to the Ranada’s model and it seems again that the quantum origin of the $\beta$ and $\gamma$ coefficients is hard to be meaningful.

However, Ranada begins the discussion in quantum footing but, for obtaining the results after writing the relations (3) and (4), he treats classically. The dependency of the light speed on the gravitational potential as Ranada himself pointed \[9\] is not a new matter. In usual general relativity, also one can write the relation $c = c_0(1 + \Delta \Phi/c^2)$ depends on the light speed definition. ($c$ is the light speed in the gravitational potential and $c_0$ is the usual light speed.) On the other hand, one can write at first the relation (3) and (4) without the using of quantum mechanics then the Ranada’s results can be obtained directly from the general relativity.

Finally, as pointed in the previous section, $\xi$ is of order $10^{-5}$ and with respect to Webb’s result $\Delta \alpha/\alpha$ is of the same order, too. Also, we can see that the order of $\Delta \alpha/\alpha$ depends only on the $\xi$ term, because the $F(t)\Phi_0/2c^2$ term is of order one. Therefore, it seems that the coincidence between relation (4) and Webb’s result is only due to adjusting $\xi$.

References

[1] J. Webb et. al., Phys. Rev. Lett. 82, 884 (1999).
[2] J. Webb et. al., Phys. Rev. Lett. 87, 091301 (2001).
[3] A. Peres, Int. J. Mod. Phs. D12, 1751 (2003).
[4] J. D. Anderson et. al., Phys. Rev. Lett. 81, 2858 (1998).
[5] J. D. Anderson et. al., Phys. Rev. D65, 082004 (2002).
[6] J. D. Ranada, Europhys. Lett. 61, 174 (2003).
[7] J. D. Ranada, Int. J. Mod. Phs. D12, 1755 (2003).
[8] J. D. Ranada, Europhys. Lett. 63, 653 (2003).
[9] J. D. Ranada, “On the Pioneer acceleration as light acceleration”, arXiv: gr-qc/0403013
[10] P. Teyssandier,“Variation of the speed of light due to non-minimal coupling between electromagnetism and gravity”, arXiv: gr-qc/0303081
[11] I. T. Drummond and S. J. Hathrell, Phys. Rev. D22,343 (1980).