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Nikola Perkovic*

Institute of Physics and Mathematics, Faculty of Science, Univeristy of Novi Sad, Serbia

E-mail address perce90gm@gmail.com

Abstract

We will define the mass of an electron in the context of Weinberg's empirical formula that relates the mass of a pion to fundamental physical constants, namely the gravitational and Planck constants, the speed of light in vacuum and the Hubble constant. After redefining the Weinberg formula to apply for electrons instead of pions we will add density parameters, used in modern Cosmology, to the Hubble constant in an attempt to persevere the universality of free fall which is one of the corner stones of General Relativity. Universality of free fall is not violated if fundamental physical constants do not vary with time which will be demonstrated in the aforementioned empirical formula for the electron mass and thus, subsequently the proton-to-electron mass ratio, the fine structure constant as well as for the gravitational constant.

Keywords

Large Number Hypothesis, Cosmology, Hubble Constant, Fine-structure constant

1. Introduction

Large number formulas pointed out by Dirac [1] have attracted the attention of physicists for almost a century, however none so much as the well-known empirical formula pointed out by Weinberg [2] that relates the mass of pions with certain fundamental physical constants.

$$m_\pi \approx \left(\frac{\hbar^2}{Gc} H_0\right)^{1/3} \qquad (1)$$

where m_π is the rest mass of a pion, ħ is the reduced Planck constant, G is the gravitational constant, c is the speed of light and H_0 is the Hubble constant. There is a problem with the formula from equation (1), namely the problem is that the right side of the equation provides a value of approximately $60\ \mathrm{MeV \cdot c^{-2}}$ for a value of H_0 that Weinberg used, whereas the mass of a charged pion is slightly bellow $140\ \mathrm{MeV \cdot c^{-2}}$ and a neutral pion is even lighter with a mass of approximately $135\ \mathrm{MeV \cdot c^{-2}}$. This empirical formula would indicate that the gravitational constant and therefore the pion mass aren't "proper" constants but they vary with time. The second indication of the formula is that there is something special about pions in General Relativity, physical Cosmology and studies of Quantum Gravity which shouldn't be the case as pions are a rather small fraction of the matter-energy content of the universe which should mean that virtual pions in the vacuum should come in an extensive presence. According to Quantum Field Theory virtual particles are an inherent part of vacuum fluctuations however it is electron-positron pairs and other charged lepton anti-lepton virtual particle pairs as well as gauge bosons such as photons that seem to be dominant in the QED vacuum not virtual pions albeit virtual pion pairs are a part of the QCD vacuum but even then there are plenty of other mesons and baryons, collectively known as hadrons. On the other hand one could assume that the formula is a mere coincidence. The Hubble Parameter H is a function of the age of the universe and thus it is not a constant but it varies with cosmological time. This drew many physicists to believe that the gravitational constant and maybe the mass of the pion as well, could also vary with time on a cosmological scale. We will demonstrate the opposite and rewrite the equation to connect the fine structure constant, the electron mass and the gravitational constant with the other fundamental physical constants from the equation.

2. The Electron Formula

Pions are pseudoscalar mesons that come in three types: two charged pions that are each other's anti-particles and a neutral pion that is its own anti-particle. As mesons, they are formed out of a quark and an anti-quark. Rest energy of a pion can be defined as:

$$m_\pi \cong \frac{2m_e}{\alpha(0)} \qquad (2)$$

Where m_e is the mass on an electron and $\alpha^{-1}(0) = 137.035999139(31)$ is the fine structure constant with the current value provided by NIST [3]. We have ignored the running of the fine structure constant for the sake of simplicity since the right side of equation (2) provides a value of around $140\ \mathrm{MeV} \cdot c^{-2}$ which is very close to the experimental value of pion mass. Now we can rewrite the Weinberg formula as so that we obtain an empirical formula for the electron mass:

$$m_e = \left(\frac{\alpha^3(0)\,\hbar^2}{8Gc} H_0\right)^{1/3} \qquad (3)$$

which is far more accurate than the Weinberg formula. The three quantities, namely the electron mass (proton-to-electron mass ration), the fine structure constant and the gravitational constant are the ones that are hypothesized to vary over cosmological temporal scales [4] as well as the fact that this empirical formula requires large quantities of electrons and virtual electron-positron pairs. However there is still a problem passed on from Weinberg's formula, namely the right side of the equation still depends on time and therefore requires varying constants. As D. Slavkov Hajdukovic points out [5] the right hand side of the Weinberg formula doesn't need to vary with time if we rewrite it to include density parameters:

$$m_e = \left[\frac{\alpha^3(0)\hbar^2}{Gc} H \left\{\frac{\Omega_\Lambda}{(\Omega - 1)^{1/2}} \cdot \frac{R_0}{R}\right\}\right]^{1/3} \qquad (4)$$

where R is the scale factor in the FRW metric, Ω is the total energy density relative to critical density and Ω_Λ is the density parameter for the cosmological constant Λ as a candidate for dark energy. The right side of the formula is now independent of time therefore it is a good example of non-varying constants.

3. Conclusions & Debate

Equation (4) makes a strong argument that can finally end the debate started by Dirac's large number hypothesis (LNH) on the possibility that physical constants vary with time and it could also help answer one of the largest mysteries in physics, namely why doesn't the zero point energy of the vacuum cause a larger cosmological constant than observed [6], [7]. Equation (4) predicts a far more accurate value of the cosmological constant than any previous work than connected elementary particles and the cosmological constant. As J. P. Uzan points out in [8] any of the aforementioned constants varying even slightly would mean the existence of an almost massless field that couples to matter which would cause a violation of the universality of free fall, challenging the validity of general relativity. If the fundamental constants truly do not vary with time as equation (4) predicts then the universality of free fall is not violated.

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References

[1] P.A.M. Dirac, Nature, 139 (1937) 323.

[2] S. Weinberg, Gravitation and Cosmology, John Wiley and Sons, New York, (1972) 620.

[3] Particle Data Group Collaboration, Review of Particle Physics, Chin. Phys. C 40, no. 10, 100001 (2016).

[4] Peter J. Mohr et al, CODATA Recommended Values of the Fundamental Physical Constants (2010).

[5] D. Slavkov Hajdukovic, On the relation between mass of a pion, fundamental physical constants and cosmological parameters, PH Division CERN (2008). arXiv:0810.4678v4

[6] Steinhardt, P. and Turok, N. Why the Cosmological constant is so small and positive? Science. 312: 1180–1183 (2006). arXiv:astro-ph/0605173

[7] Wang, Qingdi, Zhu, Zhen, Unruh, William G. How the huge energy of quantum vacuum gravitates to drive the slow accelerating expansion of the Universe. Physical Review D. 95 (10): 103504 (2017). arXiv:1703.00543

[8] J. P. Uzan, Varying Constants, Gravitation and Cosmology, Living Rev. Relativity, 14, (2011), 2.