Journal of Modern Physics, 2022, 13, 1519-1524
https://www.scirp.org/journal/jmp
ISSN Online: 2153-120X
ISSN Print: 2153-1196

Electron Mass Is Specified by Five Fundamental Constants, α, $\hbar$, G, Λ, and Ω_Λ, from Quantum Mechanics and General Relativity

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How to cite this paper: Mongan, T.R. (2022) Electron Mass Is Specified by Five Fundamental Constants, α, $\hbar$, G, Λ, and Ω_Λ, from Quantum Mechanics and General Relativity. *Journal of Modern Physics*, **13**, 1519-1524.
https://doi.org/10.4236/jmp.2022.1312093

Received: November 8, 2022
Accepted: December 18, 2022
Published: December 21, 2022

Abstract

Electron mass has been considered a fundamental constant of nature that cannot be calculated from other constants such as Planck's constant $\hbar$ and gravitational constant G. In contrast, holographic analysis takes account of the finite amount of information available to describe the universe and specifies electron mass to six significant figures in terms of five fundamental constants: fine structure constant α, $\hbar$, G, cosmological constant Λ, and vacuum fraction Ω_Λ of critical density. A holographic analysis accounts for charge conservation, mass quantization, and baryon/antibaryon ratio. A holographic analysis relates electromagnetism and gravitation, specifies electron Compton wavelength in terms of Planck length and cosmological event horizon radius, and has implications for charged Standard Model fermion masses, minimum stellar mass at redshift z, and use of continuum mathematics in a discontinuous universe.

Keywords

Electron Mass, Fundamental Constants, Holographic Analysis

1. Introduction

At present, all visible matter in our universe is thought to be composed of the twelve fundamental fermions in the Standard Model of particle physics. Of the twelve fundamental fermions, only electrons exist independently for indefinite times. It has long been thought that electron mass cannot be calculated from the fundamental constants of nature, so the electron mass itself must be a fundamental constant of nature. In contrast, this holographic analysis, based on quantum mechanics, general relativity, black hole thermodynamics, and Shannon information theory, shows electron mass is determined to six significant figures by five fundamental constants of nature: fine structure constant α, Planck's constant $\hbar$, Newton's gravitational constant G, cosmological constant Λ, and vacuum fraction Ω_Λ of the critical density of the universe.

In the analysis, Particle Data Group [1] values are used for electron mass $m_e = 9.109384 \times 10^{-28}\ \text{g}$, fine structure constant $\alpha = \frac{e^2}{\hbar c} = 7.297353 \times 10^{-3}$, Planck's constant $\hbar = 1.054572 \times 10^{-27}\ \text{g} \cdot \text{cm}^2/\text{sec}$, gravitational constant $G = 6.67430 \times 10^{-8}\ \text{cm}^3/(\text{g} \cdot \text{sec}^2)$, cosmological constant $\Lambda = 1.088 \times 10^{-56}\ \text{cm}^{-2} \pm 2.8\%$, and vacuum fraction $\Omega_\Lambda = 0.685 \pm 1.0\%$ of critical density.

2. Holographic Analysis

Our vacuum-dominated universe is so large it is indistinguishable from flat Euclidean space [2] [3], has critical density, a cosmological constant Λ, and an event horizon radius $R_H = \sqrt{\frac{3}{\Lambda}} = 1.661 \times 10^{28}\ \text{cm}$. Holographic analysis [4] finds only a finite amount of information, proportional to horizon area, available to describe the universe. The number of bits of information available is $N = \frac{\pi}{\ln(2)}\left(\frac{R_H}{l_P}\right)^2 = 4.741 \times 10^{122}$ where Planck length $l_P = \sqrt{\frac{\hbar G}{c^3}} = 1.61625 \times 10^{-33}\ \text{cm}$. In today's universe, with Hubble parameter H_0, matter density $\rho_m = (1-\Omega_\Lambda)\rho_{crit}$, and critical density $\rho_{crit} = \frac{3H_0^2}{8\pi G}\ \text{g}/\text{cm}^3$ for flat space, matter content within event horizon is $M_H = \frac{4}{3}\pi(1-\Omega_\Lambda)\rho_{crit} R_H^3$. Friedmann's general relativistic equation $H_0^2 = \frac{8\pi G}{3}\rho_{crit} + \frac{\Lambda c^2}{3}$ for flat universe with critical density and cosmological constant defines $\Omega_\Lambda \equiv \frac{\Lambda c^2}{3H_0^2}$, and, in a flat universe, matter content within the event horizon $M_H = \frac{(1-\Omega_\Lambda)c^2}{2G\Omega_\Lambda}\sqrt{\frac{3}{\Lambda}}$ is constant in time. Quantum of mass is constant mass per bit of information $m_{bit} = M_H/N = 1.08 \times 10^{-67}\ \text{g}$, differing by dimensionless factor $2\pi^2$ from Wesson's dimensional analysis [5]. In a fundamental sense, information specifies distribution of matter in space.

3. Equation for Electron Mass

Electron holographic radius can be defined as radius $r_e = \sqrt{\frac{m_e}{M_H}} R_H$ of a spherical holographic screen accommodating $N_e = \frac{\pi}{\ln(2)}\left(\frac{r_e}{l_P}\right)^2$ bits of information. Electrostatic potential energy of electron charge e and positron charge $-e$ separated by distance $2r_e$ is $V=-\frac{e^2}{2r_e}=-\frac{\alpha\hbar c}{2r_e}$. Two adjacent spheres with holographic radius r_e, a precursor for electron-positron pair production, have total energy $E=2m_ec^2-\frac{\alpha\hbar c}{2r_e}=0$ when $r_e=\frac{\alpha\hbar c}{4m_ec^2}$. Two equations for r_e result in $\frac{\alpha\hbar c}{4m_ec^2}=\sqrt{\frac{m_e}{M_H}}R_H$ and the equation for electron mass

$$m_e=\left[\left(\frac{(\alpha\hbar)^2}{32}\right)\left(\frac{1-\Omega_\Lambda}{G\Omega_\Lambda}\sqrt{\frac{\Lambda}{3}}\right)\right]^{1/3}.$$

Particle Data Group values indicate electron mass 0.5% higher than actual electron mass to three significant figures. Setting $\Lambda=1.08800\times10^{-56}\ \text{cm}^{-2}$ and increasing Ω_Λ by 0.5% to 0.6883855%, within Particle Data Group error bars, specifies electron mass to six significant figures. Gravitational constant G is only known to six significant figures and the calculation cannot be extended to greater precision until G is measured more precisely.

Writing electron mass equation as $\lambda_e^3=\frac{2^5}{\alpha^2}\left(\frac{\Omega_\Lambda}{1-\Omega_\Lambda}\right)l_P^2\sqrt{\frac{3}{\Lambda}}$ relates electron Compton wavelength $\lambda_e=\frac{\hbar}{m_ec}$ to horizon radius $R_H=\sqrt{\frac{3}{\Lambda}}$ and Planck length $l_P=\sqrt{\frac{\hbar G}{c^3}}$ (the Compton wavelength of Planck mass m_P).

4. Charge, Baryon/Antibaryon Ratio, and Entanglement

Describing Standard Model particles as spheres with volume, surface, and one-dimensional components [6] rather than point particles, requires neutrino mass and allows only three fermions in each charge state. Denoting low energy state of an information bit as $+\frac{e}{6}$ and high energy state as $-\frac{e}{6}$ is equivalent to defining electric charge. A charge neutral universe has equal numbers of $+\frac{e}{6}$ and $-\frac{e}{6}$ bits, as it must if it began by a quantum fluctuation from nothing. Holographic analysis of such a universe embodies charge conservation, a precondition for gauge invariance and Maxwell's equations of electromagnetism.

Independently existing positive and negative particles differ by six bits, regardless of details of how information bits specify electrons and positrons, or protons and anti-protons. Difference in six bits with mass ~10^{-67} g is consistent with particles and anti-particles, all with mass >10^{-27} g, having identical mass to one part in 10^{40}. More protons than anti-protons are in the universe [7], because $+\frac{e}{6}$ bits have lower energy than $-\frac{e}{6}$ bits, so charge neutrality requires more electrons than positrons in the universe.

Electric charge on spherical Standard Model particles must be concentrated on their surface at the spin axis [8] to avoid loss of energy from charge acceleration by particle rotation. Particle spin axis then determines particle bit configurations on opposite hemispheres of the event horizon. Electron-positron pair production produces a system with a particle at one end of the system moving in the opposite direction from an anti-particle at the other end of the system. When spin orientation at one end of the system is measured, angular momentum conservation guarantees opposite spin orientation at the other end of the system no matter how far away it is. There is nothing mysterious about this "entanglement" and no need for communication, at any speed, between two ends of the single system.

5. Discussion

The five fundamental constants in the electron mass equation occur in the product of electromagnetic factor $\left(\frac{(\alpha\hbar)^2}{32}\right)$ and gravitational factor $\left(\frac{1}{G}\sqrt{\frac{\Lambda}{3}}\frac{1-\Omega_\Lambda}{\Omega_\Lambda}\right)$. Electromagnetism and quantum mechanics involve electric charge *e*, incorporated in fine structure constant $\alpha = \frac{e^2}{\hbar c}$, as a coupling constant and Planck's constant $\hbar$ specifying quantum nature of light and matter. Gravitation determines the nature of space in general relativity using gravitational constant *G*, cosmological constant Λ, and vacuum fraction Ω_Λ of critical density.

Analysis describing Standard Model fermions as spheres [6] with volume, surface, and one-dimensional components, requires neutrino mass, allows only three fermions in each charge state, and relates all charged fermion masses to electron mass.

Holographic analysis accounts for minimum mass $M_{\min *}(z)$ of stellar systems at redshift *z*. $M_{\min *}(z)$ is estimated [9] by setting escape velocity of protons on holographic screens for stellar systems equal to average velocity of protons in equilibrium with cosmic microwave background radiation outside the screen, resulting in $M_{\min *}(z) = \left(\frac{R_H^2}{M_H}\right)\left(\frac{1.5k(1+z)2.7255}{Gm_p}\right)^2 g$ with proton mass m_p, Boltzmann constant *k*, and today's cosmic microwave background temperature 2.7255 degrees K [1]. If outgoing protons near the holographic screen are in equilibrium with outgoing photon flow from stars, stars must have mass at or above minimum stellar mass to appear as stars against the cosmic microwave background radiation. Maximum stellar mass of $300M_\odot$ [10], where $M_\odot$ is solar mass, coincided with minimum stellar mass at $z \approx 64$, consistent with indications stars first formed at $z \approx 64$ [11]. Minimum stellar mass at $z = 0$ is $> 0.07M_\odot$, consistent with smallest stellar masses [12].

Classical geometry assumes lines are infinitely divisible continua of points, because discontinuities are invisible at macroscopic scales. Infinite information in a continuous universe is implied by the infinite number of points associated with real numbers on a line between zero and one. In contrast, holographic analysis finds only $N \approx 10^{122}$ bits of information are available to describe our vacuum dominated universe. The continuum assumption introduced many mathematical and philosophical problems, associated with infinities, infinitesimals, and singularities of continuum mathematics, that are irrelevant in our discontinuous universe. A continuum *approximation* is not a continuum *assumption*, so approximating physical systems with many degrees of freedom as continuous allows use of calculus and differential equations.

6. Conclusion

This paper presents a holographic analysis calculating the electron mass from five of the fundamental constants of nature. The conclusion is simple and straightforward. The electron mass m_e is specified to six significant figures by $m_e = \left[\left(\frac{(\alpha\hbar)^2}{32}\right)\left(\frac{1-\Omega_\Lambda}{G\Omega_\Lambda}\sqrt{\frac{\Lambda}{3}}\right)\right]^{1/3}$, using the fine structure constant α, Planck's constant $\hbar$, Newton's gravitational constant G, the cosmological constant Λ, and the vacuum fraction Ω_Λ of the critical density of the universe.

Acknowledgements

I gratefully acknowledge the work of the legions of scientists who provided information enabling this work.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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