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A Dark Energy Paradigm: I. A Solution to the Cosmological Constant Problem to Predict Lepton Masses as Evidence

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Abstract: There are two major proposed forms of dark energy: the cosmological constant [1,2] and the quintessence scalar field [3–8]. However, the former has the cosmological constant problem [9–11] and the latter does not have observational evidence to support the theory [12]. In this paper, we propose a dark energy paradigm to solve the cosmological constant problem and to predict lepton masses as evidence. The dark energy paradigm is a unified dark sector [13–15] that is based on Planck's dimensional analysis, ΛCDM, energy conservation, and force equilibrium. We find that dark energy can vary from the cosmological constant to the Planck scale. We find that the predicted values of lepton masses based on the dark energy paradigm agree with the observed values to 1% (or within error ranges). Furthermore, we find that the dark energy paradigm has evidence of "dark matter predicting galactic dynamics" which is presented in an accompanying paper [16].

Keywords: cosmological constant; lepton mass; dark energy paradigm; unified dark sector; Planck's dimensional analysis

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In cosmology, the cosmological constant problem or vacuum catastrophe is the disagreement between the observed small value of dark energy density and the theoretical large value of zero-point energy suggested by quantum field theory (See Figure 1) [17–20]. In quantum mechanics, the vacuum itself should experience quantum fluctuations known as Casimir effects [21]. In gravity, those quantum fluctuations constitute energy that would add to the cosmological constant. However, this calculated vacuum energy density is many orders of magnitude bigger than the observed cosmological constant. Original estimates of the degree of mismatch were as high as 120 orders of magnitude [11]. To find a solution, some physicists resort to the anthropic principle and argue that we live in one region of a vast multiverse that has different regions with different vacuum energies [22]. Others modify gravity and diverge from the theory of general relativity. There are also proposals that the cosmological constant problem is trivial [23], is canceled [24], does not gravitate [25,26], or does not arise [27]. Many physicists argue that, due to a lack of better alternatives, proposals to modify gravity should be considered as one of the most promising routes to tackling the problem [28].

In our dark energy paradigm, there is no need to modify gravity or any other proven theories in physics. The essence of the cosmological constant problem is not in the disagreement between theoretical prediction and observed data but in the lack of a proper vacuum energy model that is supported by observable evidence.

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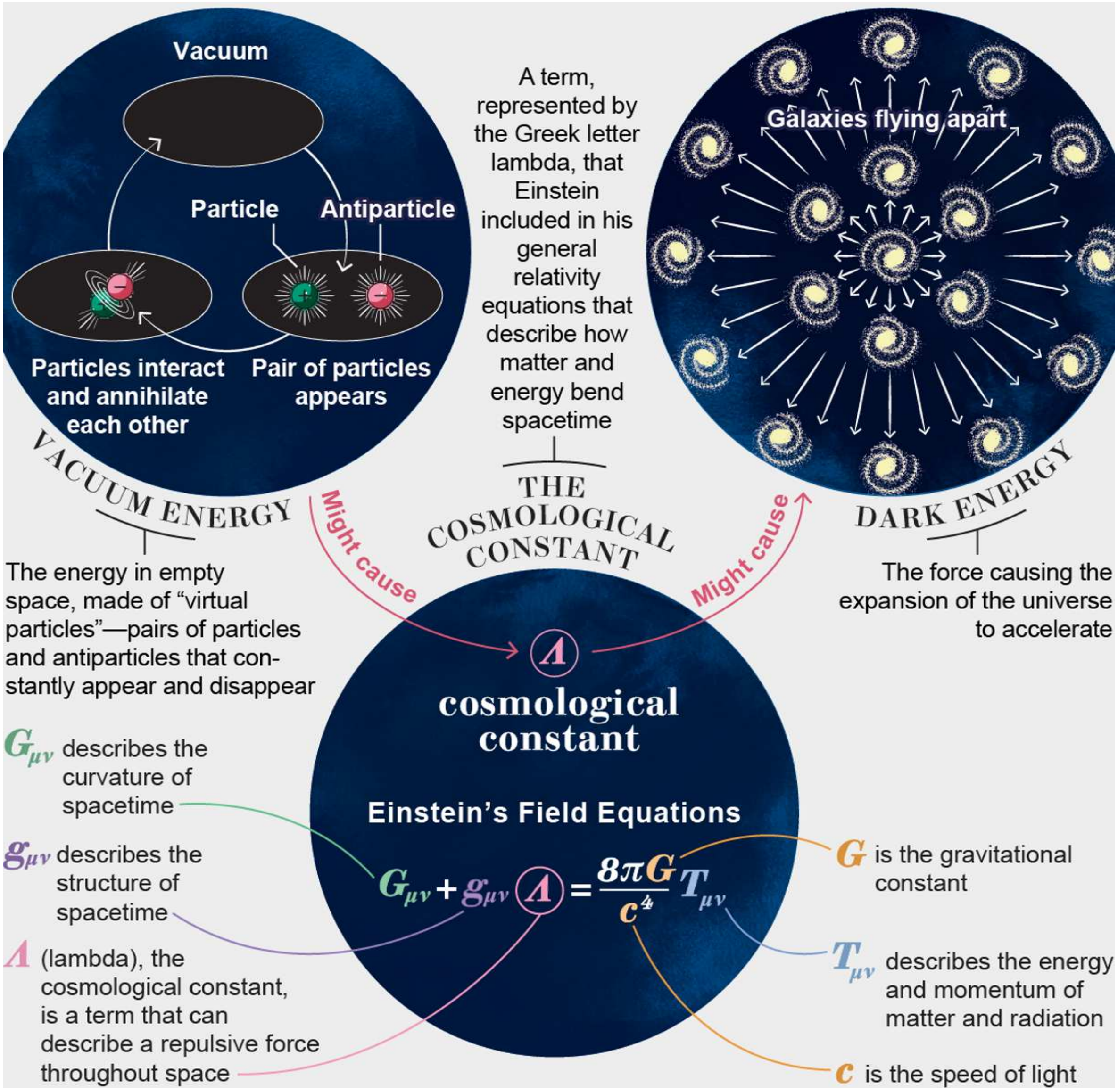

Figure 1. Cosmological constant problem due to the lack of a proper vacuum energy model. Image courtesy of Federica Fragapane and Clara Moskowitz [17]

Dark Energy Paradigm for Vacuum Energy

The dark energy paradigm is a a unified dark sector [13–15] that is based on Planck's dimensional analysis [29–33], ΛCDM [34], energy conservation and force equilibrium to explain the nature of dark energy and dark matter. In this paradigm, dark energy is similar to a photon in that its propagation speed is equal to the speed of light c, and its energy E is proportional to its frequency ω

$$c = \frac{l}{t}, \quad E = mc^2 = \hbar\omega, \tag{1}$$

where $\hbar$ is the reduced Planck constant, m is the mass equivalent to dark energy, l is the wavelength of dark energy (divided by 2π) and t is the time to travel distance l. However, dark energy is fundamentally different from a photon in that it oscillates *locally* in space, while a photon travels *globally* through space. Furthermore, a collection of dark energy particles forms a vacuum energy field or a background, which takes up about 2/3 of the energy in the universe and follows Planck's dimensional analysis.

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Planck's dimensional analysis

Planck studied vacuum energy and suggested that there exist some fundamental natural units for length, mass, time and energy. He used only the Newton gravitational constant G, the speed of light c and the Planck constant h to derive them [29–33]. The natural units became known as Planck length l_p, Planck mass m_p, Planck time t_p, and Planck energy E_p which satisfy the following equations

$$E_p t_p = \hbar, \quad p_p l_p = \hbar, \quad c = \frac{l_p}{t_p}, \quad E_p = m_p c^2 = \hbar \omega_p, \tag{2}$$

where p_p is the Planck momentum, and ω_p is the Planck frequency.

Dark energy modeled as a particle

Planck's dimensional analysis can be generalized to model dark energy as a particle with mass m, energy E, momentum p, time t, frequency ω, and wavelength l

$$Et = \hbar, \quad pl = \hbar, \quad c = \frac{l}{t}, \quad E = mc^2 = \hbar\omega, \tag{3}$$

and their zero-point values are denoted with the subscript o, which satisfy

$$E_o t_o = \hbar, \quad p_o l_o = \hbar, \quad c = \frac{l_o}{t_o}, \quad E_o = m_o c^2 = \hbar \omega_o, \tag{4}$$

where zero-point energy E_o is the lowest possible energy in a system, and vacuum energy fluctuation [35] can cause dark energy E to vary from E_o to Planck scale E_p.

In the dark energy paradigm, dark energy particles are governed by the rules of Planck's dimensional analysis on energy density, pressure, matter waves, and attractive and repulsive forces [29–33] (See Table 1). Here, a scalar field γ_p can be defined as a dimensionless parameter (See Equation (3))

$$\gamma_p = \frac{E}{E_p} = \frac{m}{m_p} = \frac{p}{p_p} = \frac{l_p}{l} = \frac{t_p}{t} = \frac{\omega}{\omega_p}, \tag{5}$$

and γ_o can be defined as a dimensionless constant (See Equation (4))

$$\gamma_o = \frac{E_o}{E_p} = \frac{m_o}{m_p} = \frac{p_o}{p_p} = \frac{l_p}{l_o} = \frac{t_p}{t_o} = \frac{\omega_o}{\omega_p}, \tag{6}$$

which corresponds to the cosmological constant Λ of the ΛCDM model.

Dark Energy Modeled with ΛCDM

The dark energy can be modeled to be consistent with ΛCDM whose pressure P_Λ is

$$P_\Lambda = -\rho_\Lambda c^2, \tag{7}$$

where ρ_Λ is the dark energy density of ΛCDM. In Planck's dimensional analysis, the repulsive force F_o is (See Table 1)

$$F_o = \frac{G\hbar}{c} \rho_o = -P_o A_p, \tag{8}$$

where ρ_o is the dark energy density of the dark energy paradigm, P_o is the force per unit area and $A_p = 4\pi l_p^2$ is the spherical Planck area. Thus, P_o is

$$P_o = -\frac{F_o}{A_p} = -\frac{G\hbar}{c}\frac{\rho_o}{4\pi l_p^2} = -\frac{\rho_o}{4\pi}c^2, \tag{9}$$

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where $G\hbar/c = l_p^2 c^2$ from Planck's dimensional analysis [29–33]. Assuming P_o is equal to the ΛCDM pressure P_Λ, P_o is (See Equation (7))

$$P_o = -\frac{\rho_o}{4\pi}c^2 = -\rho_\Lambda c^2 = P_\Lambda. \tag{10}$$

After rearranging the terms, ρ_o in terms of ρ_Λ is

$$\rho_o = 4\pi\rho_\Lambda, \tag{11}$$

where 4π accounts for the difference between Planck's dimensional analysis and ΛCDM in modeling surface under pressure (spherical surface A_p vs. flat surface). Here, the dark energy density ρ_Λ of ΛCDM is [34]

$$\rho_\Lambda = \frac{3H_0^2}{8\pi G}\Omega_\Lambda \approx \frac{H_0^2}{4\pi G}, \tag{12}$$

where H_0 is the Hubble constant, and Ω_Λ is the dark energy fraction estimated to be about 0.68 from Planck 2018 results [34]. Thus, ρ_o is

$$\rho_o = 4\pi\rho_\Lambda \approx \frac{H_0^2}{G}, \tag{13}$$

where inserting $G = 1/(t_p^2\rho_p)$ from Planck's dimensional analysis [29–33] yields

$$\rho_o = (H_0 t_p)^2 \rho_p, \tag{14}$$

and ρ_o in terms of m_o is (See Table 1)

$$\rho_o = \frac{m_o}{l_o^3} = (\frac{m_o}{m_p})^4 \rho_p = \gamma_o^4 \rho_p, \quad \gamma_o = \sqrt{H_0 t_p}, \tag{15}$$

where $l_o = l_p m_p / m_o$ is inserted (See Equation (6)). On the other hand, H_0 which minimizes the difference between the predicted and observed electron masses is (See Equation (33))

$$H_0 = 72.67\ km/s/Mpc, \tag{16}$$

which is within the converged value of observed data using calibrated distance ladder techniques of the Hubble tension ($H_0 = 73.04 \pm 1.04\ km/s/Mpc$) [34,36–39]. Thus, γ_o is

$$\gamma_o = \sqrt{H_0 \tau_p} = 3.6 \times 10^{-31}, \tag{17}$$

and m_o is

$$m_o = \gamma_o m_p = 4.3 \times 10^{-9} MeV, \tag{18}$$

where all lepton masses can be predicted based on the Hubble constant (See Table 2 and Table 3), which will be described in the following section.

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Table 1. Planck's dimensional analysis

	Planck units	dark energy (zero-point)
matter wave	$p_p l_p = m_p c l_p = \hbar$	$p_o l_o = m_o c l_o = \hbar$
energy density	$\rho_p = \frac{m_p}{l_p^3}$	$\rho_o = \frac{m_o}{l_o^3} = \gamma_o^4 \rho_p$
attractive force	$F_p = G\frac{m_p^2}{l_p^2}$	$F_o = G\frac{m_o^2}{l_o^2}$
repulsive force	$F_p = G\frac{\hbar}{c}\rho_p$	$F_o = G\frac{\hbar}{c}\rho_o$
spherical Planck area	$A_p = 4\pi l_p^2$	$A_p = 4\pi l_p^2$
pressure (force per area)	$P_p = -F_p/A_p$	$P_o = -F_o/A_p$

The dark energy paradigm is a generalization of Planck's dimensional analysis [29–33], where dark energy can vary from zero-point to Planck scale.

Table 2. Equations of three generations to predict Λ and lepton masses

	particle	neutrino ν	electron e
γ_o	Λ	$\sqrt{H_0 t_p}$	
γ_1	ν_e, e	1	
γ_2	ν_μ, μ	$1/(9\alpha^4)^{\frac{1}{3}}$	$1/(3\alpha^3)^{\frac{1}{4}}$
γ_3	ν_τ, τ	$2^{\frac{1}{8}}\gamma_2^{\frac{5}{4}}$	
m_o	Λ	$m_p \gamma_o$	
m_1	ν_e, e	m_o/α	$m_o/3\alpha^4$
m_2	ν_μ, μ	$\alpha\gamma_2^3 m_1$	
m_3	ν_τ, τ	$\alpha\gamma_3^3 m_1$	

The same generation shares the same equation between neutrino and electron except γ_2 and m_1. γ is the Lorentz factor in particle creation. Subscript o represents zero-point dark energy (the lowest possible energy in a system). Subscript 1, 2 and 3 represent generation 1, 2 and 3, respectively. γ_2 is 339.7 for a neutrino and 30.4 for an electron. γ_3 is 1590.1 for a neutrino and 77.9 for an electron. $H_0 = 72.67\ km/s/Mpc$, $\alpha \approx 1/137$.

Prediction of Lepton Masses as Evidence

Leptons and quarks come in three sets of nearly-identical copies except mass. It has been one of the mysteries of modern physics why there are three generations of particles, rather than fewer or more [40].

Origin of three generations

In the dark energy paradigm, three generations are caused by 3-dimensional interaction among a particle, an antiparticle and dark energy particles where energy density can be represented as

$$\rho = \frac{m}{l_r l_\theta l_\phi}, \tag{19}$$

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where m is mass, and l_r, l_θ and l_ϕ are dark energy wavelength in r, θ and ϕ directions respectively. As shown in Figure 2, the 1^{st} generation is simply described by 1-dimensional interaction of a particle at the origin o with its antiparticle at r. On the other hand, the 2^{nd} generation involves 2-dimensional interaction of a particle with its relativistic dark energy particle at θ. Finally, the 3^{rd} generation requires 3-dimensional interaction of a particle with dark energy particles at θ and ϕ, where the dotted line represents the vector sum of θ and ϕ directional interactions.

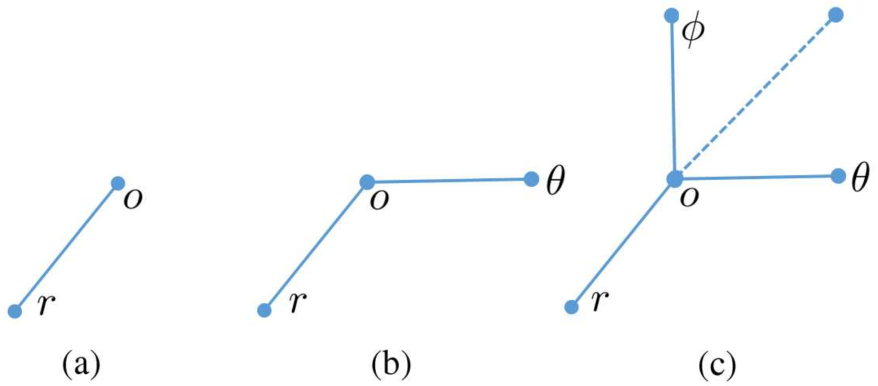

Figure 2. Origin of three generations caused by 1, 2, and 3-dimensional interactions of a particle at the origin o with an antiparticle and dark energy particles at r, θ, and ϕ in the spherical coordinate system. (a) 1-dimensional interaction with an antiparticle at r. (b) 2-dimensional interaction with a relativistic dark energy particle at θ. (c) 3-dimensional interaction with dark energy particles at θ and ϕ. A dotted line represents the vector sum of θ and ϕ directional dark energy interactions.

Energy conservation and force equilibrium

The conservation of energy states that the total energy of an isolated system remains constant. In the dark energy paradigm, the equal amount of dark energy is needed for a particle to be created in the vacuum. Dark energy can have only a certain energy value in force equilibrium which corresponds to a particle's mass. The process for predicting a mass consists of three steps. First, the velocity v and the Lorentz factor γ are obtained and inserted into the matter wave equation $\gamma mvl = \hbar$. Second, the equation is rearranged so that mass m and wavelength l can be derived from v and γ. Third, the dark energy density $\rho = m/l^3$ is evaluated in force equilibrium to predict the particle's mass m. Sometimes mass m can be directly obtained and the steps can be further simplified.

Table 3. Predicted vs. observed lepton masses

mass	particle	predicted	observed	difference
m_{ν_e}	ν_e	6.0×10^{-7}	$\leq 8.0 \times 10^{-7}$	◯
m_{ν_μ}	ν_μ	0.17	≤ 0.17	◯
m_{ν_τ}	ν_τ	17.5	≤ 18.2	◯
m_e	e	0.511	0.511	**0.000**
m_μ	μ	105.105	105.658	**−0.005**
m_τ	τ	1766.622	1776.860	**−0.006**

If any one of the masses is known (such as m_e), all the rest of the masses can be calculated. Observed data of e, μ, and τ are from the particle data group [41]. Observed data of ν_e, ν_μ and ν_τ are from the KATRIN Collaboration [42], Assamagan et al. [43] and ALEPH Collaboration [44], respectively. '◯' means the prediction within the observed range. 'Difference' means the normalized difference between predicted and observed data. Mass units are in MeV.

The 1^{st} *generation lepton masses*

For the 1^{st} generation, the matter wave equation is

$$\gamma_1 m_1 v_1 l_1 = \hbar, \tag{20}$$

where v_1 at the creation of a lepton is the same as the velocity of an electron in the Bohr model (See Methods)

$$v_1 = \alpha c, \tag{21}$$

where $\alpha \approx 1/137$ is the fine structure constant, and the Lorentz factor γ_1 is

$$\gamma_1 = \frac{1}{\sqrt{1-(v_1/c)^2}} \approx 1. \tag{22}$$

Since a neutrino at creation is expected to have the same wavelength of dark energy in force equilibrium (See Methods), l_1 is

$$l_1 = l_o, \tag{23}$$

and p_1 is

$$p_1 = \hbar/l_1 = \hbar/l_o = p_o = m_o c. \tag{24}$$

Thus, the electron neutrino's mass is (See Equation 18)

$$m_{ve} = m_1 = p_1/v_1 = m_o/\alpha = 6.0 \times 10^{-7} MeV, \tag{25}$$

where m_1 is within the observed range of a neutrino (See Table 3), and the energy density is

$$\rho_{v_e} = \rho_r = \frac{m_o/\alpha}{l_o^3} = \rho_o/\alpha, \tag{26}$$

which is generated by the 1-dimensional interaction between a neutrino and its antineutrino as shown in Figure 2(a). According to the particle data group, a neutrino consists of three eigenstates whose masses are unknown [41]. If each eigenstate is assumed to have the same mass at particle creation, the mass of a neutrino's eigenstate is 1/3 of an electron neutrino's mass, and the energy density is

$$\rho_r/3 = \frac{m_o/3\alpha}{l_o^3} = \rho_o/3\alpha, \tag{27}$$

which is 1/3 of the neutrino's density.

As a next step, if a neutrino gets excited where v_1 is close to the speed of light, the matter wave equation becomes

$$\gamma_1 m_1 v_1 l_1 = (m_o/\alpha)c(l_o\alpha) = \hbar, \tag{28}$$

where $\gamma_1 = 1$, $m_1 = m_o/\alpha$ and the wavelength changes to

$$l_o \rightarrow l_o\alpha, \tag{29}$$

and the density of one excited eigenstate is (See Equation (27) and Equation (29))

$$\rho_e = \frac{m_o/3\alpha}{(l_o\alpha)^3} = \frac{m_o/3\alpha^4}{l_o^3} = \rho_o/3\alpha^4, \tag{30}$$

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where $m_o/3\alpha^4$ is excited dark energy to create an electron, and l_o is the wavelength of dark energy in force equilibrium (See Methods). Thus, the electron mass is

$$m_e = m_1 = m_o/3\alpha^4 = 0.511MeV, \tag{31}$$

which agrees with the observed data (See Table 3). On the other hand, H_0 in terms of m_o is (See Equation (14))

$$H_0 = (\rho_o/\rho_p)^{1/2}/t_p = (m_o/m_p)^2/t_p, \tag{32}$$

and H_0 in terms of m_e is (See Equation (31))

$$H_0 = (3\alpha^4 m_e/m_p)^2/t_p = 72.67\ km/s/Mpc, \tag{33}$$

which shows the relation between the Hubble constant H_0 and the electron mass m_e.

The 2^{nd} generation lepton masses

For the 2^{nd} generation, the matter wave equation is

$$\gamma_2 m_2 v_2 l_2 = \hbar, \tag{34}$$

where the Lorentz factor γ_2 is

$$\gamma_2 = \frac{1}{\sqrt{1-(v_2/c)^2}}. \tag{35}$$

If m_1 gets excited where $v_2 \approx c$, the matter wave equation is rearranged as

$$m_1(\alpha c)l_1 = (\gamma_2 \alpha m_1)c(l_1/\gamma_2) = \hbar, \tag{36}$$

where m_1 and l_1 have changed to

$$m_1 \rightarrow \gamma_2 \alpha m_1, \qquad l_1 \rightarrow l_1/\gamma_2, \tag{37}$$

where l_1/γ_2 is for the length contraction, which causes m_1 to change accordingly. Here, the density in the particle's moving direction θ is

$$\rho_\theta = \frac{\gamma_2 \alpha m_1}{(l_1/\gamma_2)^3} = \frac{\alpha \gamma_2^4 m_1}{l_1^3}, \tag{38}$$

where $\alpha\gamma_2^4 m_1$ is an excited dark energy mass with l_1 as the wavelength in force equilibrium (See Methods). Assuming that an excited m_1 could become m_2 while momentum is conserved, p_2 yields

$$p_2 = \gamma_2 m_2 c = (\alpha \gamma_2^4 m_1)c. \tag{39}$$

After rearranging the terms, m_2 is

$$m_2 = \alpha \gamma_2^3 m_1, \tag{40}$$

where m_2 is a function of m_1. Likewise, when γ_2 is replaced by γ_3 (for the 3^{rd} generation), m_3 is

$$m_3 = \alpha \gamma_3^3 m_1, \tag{41}$$

where m_3 is also a function of m_1.

For an excited neutrino, if the 2^{nd} generation of a neutrino is created instead of the 1^{st} generation of an electron, the mass of a muon neutrino can be derived from Equation (31). If the energy of m_e is equally divided among three eigenstates of a muon neutrino [41], m_2 is

$$m_{\nu_\mu} = m_2 = m_e/3 = m_o/9\alpha^4 = 0.17MeV, \tag{42}$$

where m_2 is within the observed range of a muon neutrino (See Table 3), and γ_2 is (See Equation 40)

$$\gamma_2 = (m_2/\alpha m_1)^{\frac{1}{3}} = 1/(9\alpha^4)^{\frac{1}{3}} \approx 339.7, \tag{43}$$

from which γ_3 and m_3 can be calculated (See Methods).

For an excited electron, the matter wave equation of the excited dark energy is

$$(\gamma_2 m_o)c(l_o/\gamma_2) = \hbar, \tag{44}$$

where m_o and l_o have changed to

$$m_o \to \gamma_2 m_o, \qquad l_o \to l_o/\gamma_2, \tag{45}$$

where l_o/γ_2 is for the length contraction, which causes the mass to change accordingly. and the density in the θ-direction is

$$\rho_\theta = \frac{\gamma_2 m_o}{(l_o/\gamma_2)^3} = \frac{\gamma_2 m_o}{l_o(l_o/\gamma_2^3)l_o} = \gamma_2^4 \rho_o, \tag{46}$$

where $l_\theta = l_o/\gamma_2^3$ represents the length contraction concentrated in the particle's moving direction. On the other hand, the density in the r-direction is

$$\rho_r = \frac{m_o}{l_1 l_o l_o} = \frac{l_o}{l_1}\rho_o, \tag{47}$$

where $l_r = l_1$ is the wavelength contraction due to the charge interaction of a particle and an antiparticle. In order for the repulsive forces to be in force equilibrium, $F_r = F_\theta$ (See Table 1)

$$F_r = G\frac{\hbar}{c}\rho_r = G\frac{\hbar}{c}\rho_\theta = F_\theta, \tag{48}$$

where $\rho_r = \rho_\theta$ yields (See Equation (46) and Equation (47))

$$\rho_r = \frac{l_o}{l_1}\rho_o = \gamma_2^4 \rho_o = \rho_\theta, \tag{49}$$

and γ_2 is (See Equation (28) and Equation (31))

$$\gamma_2 = (l_o/l_1)^{\frac{1}{4}} = (m_1\alpha/m_o)^{\frac{1}{4}} = 1/(3\alpha^3)^{\frac{1}{4}} = 30.4, \tag{50}$$

and m_2 for muon is (See Equation (40))

$$m_\mu = m_2 = \alpha\gamma_2^3 m_1 = 105.105\ MeV, \tag{51}$$

which agrees with the observed data within 1% (See Table 3). It is interesting to note that the theoretical $\gamma_2 = 30.4$ at muon creation is close to the experimental $\gamma_2 = 29.3$ at the CERN muon storage ring experiment [45]. We anticipate that the dark energy paradigm could be applied in future lepton storage ring experiments. See Methods for derivation of the 3^{rd} generation of lepton masses as shown in Table 2 and Table 3.

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Conclusion

A dark energy paradigm has been presented, where predicted values of lepton masses agree with the observed values to 1% (or within error ranges). In the dark energy paradigm, a particle has the same amount of *excited* dark energy before particle creation (or after particle annihilation) due to energy conservation in the vacuum (See Figure 1). Hence, both predicted and observed lepton masses can be interpreted as the predicted and observed dark energy values. Therefore, we can argue that the predicted dark energy is equal to the observed dark energy, and the cosmological constant problem is solved for leptons (See Table 2 and Table 3). Interestingly enough, the cosmological constant problem could be solved for proton, quarks and fundamental bosons as well, which will be described in the following papers (See Methods).

Methods

Particle and antiparticle interaction

Let's assume that each fermion particle has a fractional charge e/n which generates the Coulomb force between a particle and its antiparticle. Here, all fermions share the same matter wave equation

$$pl = \gamma mvl = \hbar, \tag{52}$$

where $p = \gamma mv$ is momentum, γ is the Lorentz factor, m is mass, v is velocity, and l is wavelength (divided by 2π). Assuming a particle with e/n_1 charge and its antiparticle with e/n_2 charge form a circular orbit, the centripetal force is equal to the Coulomb force between e/n_1 and e/n_2 fractional charges (See Table 4)

$$\frac{mv^2}{l} = \frac{k(e/n_1)(e/n_2)}{l^2}, \tag{53}$$

where k is the Coulomb constant and $v \ll c$ $(\gamma = 1)$. After rearranging the terms, v is

$$v = \frac{k(e/n_1)(e/n_2)}{\hbar} = \alpha c/(n_1 n_2), \tag{54}$$

where α is the fine structure constant and $ke^2 = \hbar\alpha c$. Here, fractional charge parameters for leptons are $n_1 = n_2 = 1$, where v is

$$v = \alpha c, \tag{55}$$

which is the velocity of the 1^{st} generation of leptons. Thus, v_1 at the creation of a lepton particle has the same value as the velocity of an electron in the Bohr model. It is important to note that neutrino charge is unique in that it only interacts with neutrino charge, while electron and quark charges interact with each other.

Now the fractional charge parameters for down quarks are $n_1 = n_2 = 3$, where v is

$$v = \alpha c/9, \tag{56}$$

and fractional charge parameters for up quarks are $n_1 = 3/2$ and $n_2 = 3$, where v is

$$v = 2\alpha c/9. \tag{57}$$

Thus, fractional charges in force equilibrium play an important role in determining velocity v at the creation of a particle and antiparticle pair.

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Table 4. Fractional charge parameters for fermions

	neutrino	electron	down quark	up quark
n_1 (particle)	1	1	3	3/2
n_2 (antiparticle)	1	1	3	3
$n_1 n_2$	1	1	9	9/2

Neutrino charge is unique in that it only interacts with neutrino charge.

Particle and dark energy in force equilibrium

Let's imagine a particle and a dark energy particle at distance l with masses m and m_o, respectively. Here the attractive force is (See Table 1)

$$F_{attractive} = G\frac{mm_o}{l^2}, \tag{58}$$

and the repulsive force is

$$F_{repulsive} = G\frac{\hbar}{c}\frac{m}{l^3}. \tag{59}$$

In force equilibrium, setting $F_{attractive} = F_{repulsive}$ produces

$$G\frac{mm_o}{l^2} = G\frac{\hbar}{c}\frac{m}{l^3}, \tag{60}$$

after rearranging the terms, l is

$$l = \frac{\hbar}{m_o c}, \tag{61}$$

where inserting the matter wave equation $m_o c l_o = \hbar$ yields

$$l = l_o, \tag{62}$$

where the wavelength of a particle l is equal to the wavelength of dark energy l_o.

The 3^{rd} generation lepton masses

For the 3^{rd} generation, the matter wave equation is

$$\gamma_3 m_3 v_3 l_3 = \hbar, \tag{63}$$

where the Lorentz factor γ_3 is

$$\gamma_3 = \frac{1}{\sqrt{1-(v_3/c)^2}}. \tag{64}$$

If m_1 gets excited where $v_3 \approx c$, m_3 is (See Equation (41))

$$m_3 = \alpha\gamma_3^3 m_1, \tag{65}$$

and replacing m_1 by m_2 yields (See Equation (40))

$$m_3 = (\gamma_3/\gamma_2)^3 m_2, \tag{66}$$

where m_3 is a function of m_2.

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While the 2^{nd} generation is generated by the 2-dimensional interaction

$$\rho_r = \rho_\theta, \tag{67}$$

the 3^{rd} generation is caused by the 3-dimensional interaction (See Figure 2 and Table 5)

$$\rho_r = |\vec{\rho}_\theta + \vec{\rho}_\phi|, \tag{68}$$

where vector $\vec{\rho}$ corresponds to force vector $\vec{F}$ (See Table 1)

$$\vec{F}_\theta = G\frac{\hbar}{c}\vec{\rho}_\theta, \qquad \vec{F}_\phi = G\frac{\hbar}{c}\vec{\rho}_\phi, \tag{69}$$

where ρ_θ is dark energy density in a particle's moving direction which is under γ_2 length contraction. Thus, ρ_θ changes to (See Equation (46))

$$\rho_\theta = \frac{\gamma_2 m_o}{l_o(l_o/\gamma_2^3)(l_o/\gamma_2)} = \gamma_2^5\rho_o, \tag{70}$$

where $l_\phi = l_o/\gamma_2$ is for the additional length contraction in the ϕ direction. Assuming $\rho_\phi = \rho_\theta$ in force equilibrium, ρ_ϕ is

$$\rho_\phi = \gamma_2^5\rho_o, \tag{71}$$

and the magnitude of the vector sum is (See Equation 68)

$$\rho_r = |\vec{\rho}_\theta + \vec{\rho}_\phi| = \sqrt{2}\gamma_2^5\rho_o, \tag{72}$$

where $\sqrt{2}$ is due to the orthogonal vector sum in θ and ϕ directions (See Figure 2). Here, the matter wave equation is

$$m_o c l_o = (\gamma_3 m_o)c(l_o/\gamma_3) = \hbar, \tag{73}$$

where l_o/γ_3 represents the length contraction, and ρ_r in terms of γ_3 is

$$\rho_r = \frac{\gamma_3 m_o}{(l_o/\gamma_3)^3} = \gamma_3^4\rho_o. \tag{74}$$

Thus, the relation between γ_3 and γ_2 is

$$\rho_r = \gamma_3^4\rho_o = \sqrt{2}\gamma_2^5\rho_o. \tag{75}$$

After rearranging the terms, γ_3 is

$$\gamma_3 = 2^{\frac{1}{8}}\gamma_2^{\frac{5}{4}} = 1590.1, \tag{76}$$

where $\gamma_2 = 339.7$ (See Equation (43)), and m_3 for tau neutrino is (See Equation (66))

$$m_{\nu_\tau} = m_3 = (\gamma_3/\gamma_2)^3 m_2 = 17.5\ MeV, \tag{77}$$

where m_3 is within the observed range of a tau neutrino (See Table 3).

On the other hand, γ_3 for tau is

$$\gamma_3 = 2^{\frac{1}{8}}\gamma_2^{\frac{5}{4}} = 77.9, \tag{78}$$

where $\gamma_2 = 30.4$ (See Equation (50)), and m_3 for tau is (See Equation (51) and Equation (66))

$$m_\tau = m_3 = (\gamma_3/\gamma_2)^3 m_2 = 1766.622\ MeV, \tag{79}$$

which agrees with the observed data within 1% (See Table 3).

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Table 5. Matter wave & energy density equations for three generations

generation	mass	neutrino	electron	matter wave	energy density
1	m_1	m_{ν_e}	m_e	$\gamma_1 m_1 v_1 l_1 = \hbar$	ρ_r
2	m_2	m_{ν_μ}	m_μ	$\gamma_2 m_2 v_2 l_2 = \hbar$	$\rho_r = \rho_\theta$
3	m_3	m_{ν_τ}	m_τ	$\gamma_3 m_3 v_3 l_3 = \hbar$	$\rho_r = \lvert\vec{\rho_\theta} + \vec{\rho_\phi}\rvert$

γ is the Lorentz factor, m is mass, v is velocity, and l is wavelength (divided by 2π). ρ_r, ρ_θ and ρ_ϕ are dark energy densities in r, θ and ϕ directions, respectively (See Figure 2). $\vec{\rho}_\theta$ and $\vec{\rho}_\phi$ correspond to repulsive force vectors (See Table 1).

Dark energy paradigm for major applications

As shown in Table 6, the dark energy paradigm can be used to solve major problems in physics which will be discussed in other papers.

Table 6. List of key papers on the dark energy paradigm

	subject	contents	consistency with observed data
1	dark energy	solution to the cosmological constant problem	◯
		prediction of lepton masses	◯
2	dark matter	prediction of galactic dynamics	◯
3	cosmology	prediction of Ω_Λ, Ω_c and Ω_b distribution	◯
4	quark	prediction of quark masses	◯
5	boson	prediction of fundamental boson masses	◯
6	quantum theory	consistency with quantum theory	◯
		solution to the measurement problem	◯
7	quantum gravity	prediction of black hole properties	–

'◯' means consistency with observed data, and '–' means not enough observed data to determine consistency. To the best of the authors' knowledge, the dark energy paradigm is consistent with most, if not all, observed data in quantum theory, ΛCDM, and gravity.

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