The Quark Theory of the Electron and the Vacuum

Rami Rom[(a)]

Abstract: Paul Dirac developed a quantum theory of the electron in 1928 that led him to the discovery of antimatter in general and to the discovery of the electron antiparticle, the positron. We propose a new quark theory of the electron and the vacuum. We propose that the electron is a non-elementary, non-point like particle comprised of two quarks and two antiquarks having a tetrahedron structure. We further assume that electrons perform rapid quark flavor exchange reactions with vacuum pion tetraquark tetrahedrons comprised of the valence quarks and antiquarks, u , d , $\tilde{u}$, $\tilde{d}$ that form the quantum vacuum fabric. Motion of the electron tetraquark tetrahedron on the vacuum pion tetraquark tetrahedron fabric is performed by a u *and* d quark flavor exchange reactions by tunneling through a double well potential between the electron tetraquark tetrahedron and the vacuum pion tetraquark tetrahedron that transform the electron tetraquark tetrahedron to a pion tetraquark tetrahedron and vice versa. We assume that the quark flavor exchanges occur with Dirac's equation extremely high zitterbewegung frequency and hence a single electron cannot be isolated since it forms a delocalized electron cloud with the vacuum pion tetraquark tetrahedrons fabric.

Keywords: Antimatter, Quantum vacuum, Pion tetrahedrons, QED, QCD.

(a) Email: romrami@gmail.com

1. Problems with the Quantum Electron Theory

Dirac proposed a relativistic wave equation and found a new set of negative energy solutions he interpreted as antimatter states[1]. Dirac thought that since the positive electron solutions would decay to negative energy states there must be an infinite number of invisible electrons that occupy the negative states and prevent the decay of positive energy electrons according to Pauli exclusion principle[2]. Dirac thought that electrons may not be point like particles and proposed a charged spherical shell electron model with internal oscillations and self-energy[3]. Dirac thought that since the electron interacts always with the vacuum electron-positron virtual pairs, the electron is never bare in contrast to Feynman's QED approach[4], where in zero order bare electrons propagate in free space and then interact with other particles with perturbation theory approximation. Dirac thought that better understanding of the vacuum structure is needed to understand QED[5].

The questions we address in this paper are:

1. Are electrons non-elementary, non-point like and not a single particle made of quarks and antiquarks?
2. Is the universe quantum vacuum filled with massive pion tetraquark tetrahedrons comprised of 50% quarks and 50% antiquarks?
3. Does electrons motion occur via u and d quark flavor exchanges by tunneling reactions through a double well potential between electrons tetraquark tetrahedrons and the vacuum pion tetrahedrons in a first electron chiral state, and exchanges of $\tilde{u}$ and $\tilde{d}$ antiquark flavor exchanges in a second electron chiral state?

2. The Vacuum Pion Tetraquark Tetrahedron Fabric

We assume that the universe quantum vacuum is filled with pion tetrahedron tetraquark fabric[6-10]. We note that the vacuum pion tetrahedrons are not ordinary matter particles since they are composed of 50% antiquarks that annihilate the other 50% quarks, however, we assume that the pion tetraquark tetrahedrons still have a very small mass and internal rotation and vibration energy, and since the quarks and antiquarks are charged, the pion tetrahedrons have internal electric dipoles. We assume that in each site in the vacuum fabric there is a single tetraquark tetrahedron, $u\tilde{d}d\widetilde{u}$, composed of two valence quarks, d and $u,$ and their antiquark pairs, $\tilde{d}$and $\tilde{u}$. Two pion tetraquark tetrahedron enantiomers may exist obtained by exchanging the position of two quarks at the tetrahedron vertices as shown below in line with Dirac and Weyl massless chiral spinors and the symmetry of the ground state of the QCD vaccum[11-17].

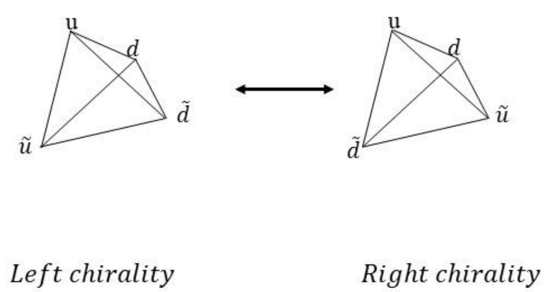

Figure 1 illustrates the two pion tetrahedron enantiomers where the $\tilde{u}$ and $\tilde{d}$ antiquarks exchange positions.

We assume that the pion tetraquark tetrahedron fabric may be a simple cubic lattice in free space. However, in the vicinity of a massive body, the pion tetraquark tetrahedron fabric may have higher density and a spherical symmetry according to gravity or electric charge. The size of the pion tetraquark tetrahedron edge may be less than a femtometer, while the pion tetrahedron fabric lattice length in outer space far from any massive body may be much larger, for example about a few Compton lengths, $\sim 10^{-13}$ meter. In extreme gravitational field, in the vicinity of a black hole for example, the pion tetraquark tetrahedron lattice cell size may become extremely small, on the scale of the pion tetrahedron edge of about $0.5 * 10^{-15}$ meter. However, far away from any galaxy in the cosmic voids[18-20], the pion tetraquark tetrahedron fabric may be extremely diluted with lattice cell size of tens or more Compton lengths.

3. The Electron Tetraquark Tetrahedron and the Vacuum Double Well Potential Model

We assume that electrons are non-elementary, non-point like particles comprised of tetraquarks having two configurations, a right chiral (spin), $\tilde{u}\, du\tilde{u}$, and a left chiral (spin), $\tilde{u}\, dd\tilde{d}$. Adding an electron to the pion tetraquark tetrahedron fabric occurs by a quark flavor exchanges in a fabric site transforming a pion tetraquark tetrahedron with one of the two chiral electron tetraquark tetrahedrons. Motion of the electron tetraquark tetrahedron on the pion tetrahedron fabric occurs via tunneling through a double well potential[21] that represents an exchange of quark flavors via gluon exchanges between the electron tetraquark tetrahedron and the pion tetraquark tetrahedron on adjacent fabric sites that transform the electron tetraquark tetrahedron to a pion tetraquark tetrahedron and vice versa. The $u\ and\ d$ quark flavors are exchanged by gluons as shown in figure 2 and equations 1 below for the left chiral state.

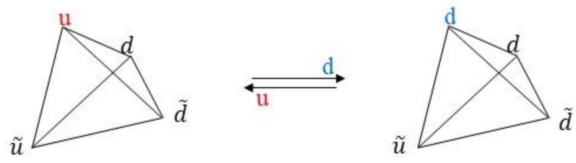

Figure 2 illustrates an electron tetraquark tetrahedron and a pion tetraquark tetrahedron exchanging quark flavors (u and d).

$$\tilde{u}d\tilde{d}u\ (\pi^{Td})_i + \tilde{u}d\tilde{d}d\ (e^L)_j \rightarrow \tilde{u}d\tilde{d}d\ (e^L)_i + \tilde{u}d\tilde{d}u\ (\pi^{Td})_j \quad (1)$$

In the case of the right chiral electron the $\tilde{u}$ *and* $\tilde{d}$ antiquarks exchange their flavor via gluon exchanges, and the quark flavor exchange reaction equation is

$$\tilde{u}d\tilde{d}u\ (\pi^{Td})_i + \tilde{u}d\tilde{u}u\ (e^R)_j \rightarrow \tilde{u}d\tilde{u}u\ (e^R)_i + \tilde{u}d\tilde{u}u\ (\pi^{Td})_j \quad (2)$$

Since the quark flavor exchange reactions are symmetric, e.g., the reactants on the left-hand-side and the products on the right-hand-side of the equation are identical, the usage of the double well potential Hamiltonian is valid[21].

$$\hat{H} = \frac{\hat{p}^2}{2m} + m\lambda\ (x^2 - a^2)^2 \quad (3)$$

We assume for the double well potential model that the mass m is the electron rest mass, a is the pion tetrahedron lattice cell size and the double well potential parameter λ determines the potential barrier height, $V_0 = m\,\lambda\, a^4$. We assume that the potential barrier height $V_0 = \hbar\boldsymbol{\omega} = 2m_e c^2$, where the frequency $\omega = \frac{2m_e c^2}{\hbar}$ is Dirac's equation free space trembling zitterbewegung[22-23]. Accordingly, the zero-order ground state energy inside the well $E_0 = \frac{1}{2}\hbar\boldsymbol{\omega} = m_e c^2 = 5.11 * 10^6\ eV$ is equal to the electron rest mass energy.

Figure 3 below illustrates the double well potential model for the electron tetraquark tetrahedron and the pion tetraquark tetrahedron quark flavor exchange reaction in adjacent lattice sites i and j in the ground state. We assume that the electron motion on the vacuum fabric is via the quark flavor exchange reactions by quantum tunneling of gluons through the potential barrier V_0 where the double well potential exists between all adjacent lattice sites in the vacuum fabric. Note that V_0 is twice the electron rest mass energy and represents the threshold for electron-positron pair production. Note that the electron tetraquarks on both sides of the double well is identical and hence the electron chiral configuration (a $\widetilde{u}\,dd\widetilde{d}$ or a $\widetilde{u}\,du\widetilde{u}$) is conserved, the two electron tetraquark tetrahedron chiral states are not mixed by the rapid quark flavor exchanges that occur with the extremely high zitterbewegung frequency in each configuration.

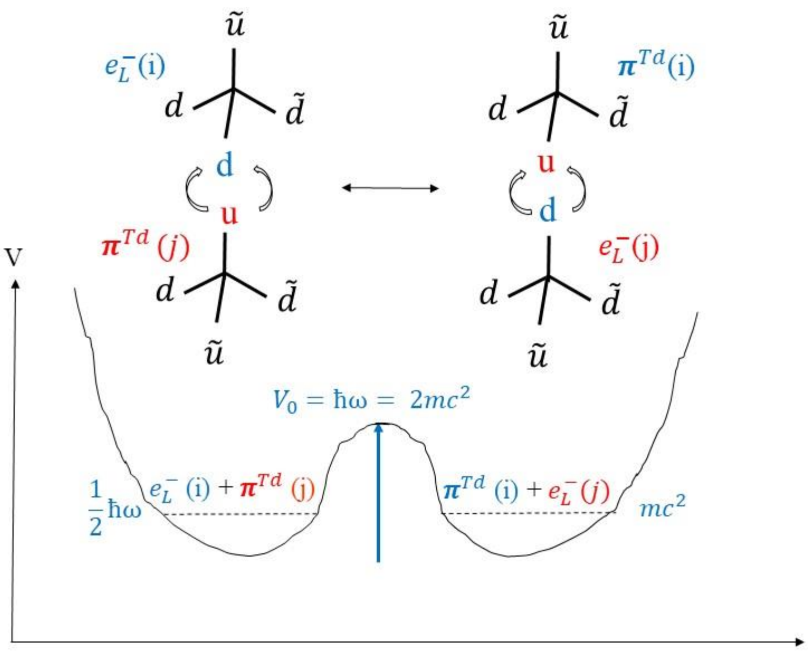

Figure 3 illustrates the double well potential model for the electron tetraquark tetrahedron and pion tetraquark tetrahedron quark flavor exchange reactions via gluons in adjacent lattice sites i and j.

The tunneling probability, T, from the first to the second potential well in the ground state through the potential barrier V_0 is calculated with a WKB approximation[21]

$$T = e^{-\left(\frac{2}{\hbar}\int_{-a}^{a}\sqrt{2m(E-V(x)}\,dx\right)} = e^{-\frac{8\,ma^3\sqrt{2\lambda}}{3\hbar}} = e^{-\frac{32V_0}{3\hbar\omega}} \qquad (4)$$

ω is the ground state frequency in each well separately given by the double well model parameters by

$$\omega = \frac{2\pi}{\tau} = \sqrt{8\,\lambda\,a^2} \qquad (5)$$

We assume that the barrier height potential V_0 may vary in space according to external or induced fields, for example the external gravitational field or the induce electrical field, and that the value of V_0 determines the average electron velocity on the vacuum pion tetrahedron fabric.

The velocity of the electron tetrahedron making a quantum tunneling transition from site i to j due to the flavor exchange reaction may be estimated by the distance between the sites, a, divided by half of the time period of the ground state oscillation in the potential well, $\tau/2$, and multiplied by the WKB tunneling probability in the ground state in the double well T[21].

$$v_e = \frac{a}{\tau/2}\mathrm{T} = \frac{a\omega}{\pi} e^{-\frac{32V_0}{3\hbar\omega}} \quad [\frac{m}{sec}] \qquad (6)$$

For the double well model the product $a\omega$ is equal to $\sqrt{\frac{8V_0}{m}}$

$$a\omega = \sqrt{8\,\lambda\, a^4} = \sqrt{\frac{8V_0}{m}} \quad [\frac{m}{sec}] \qquad (7)$$

Hence the electron velocity of equation 6 becomes

$$v_e = \frac{1}{\pi}\sqrt{\frac{8V_0}{m}}\; e^{-\frac{32V_0}{3\hbar\omega}} \quad [\frac{m}{sec}] \qquad (8)$$

With $\lambda = \frac{m^2c^4}{2\,\hbar^2 a^2}$, $V_0 = \mathrm{m}\,\lambda\, a^4 = \frac{m^3c^4a^2}{2\,\hbar^2}$ and the Compton length $\lambda_C = \frac{\hbar}{\mathrm{m\,c}}$ the electron velocity according to equation 8 may be re-written in terms of the lengths ratio $r_c = \frac{a}{\lambda_C}$

$$v_e = \frac{2}{\pi}\sqrt{c^2 r_C^2}\; e^{-\frac{8}{3}r_C^2} \quad [\frac{m}{sec}] \qquad (9)$$

The electron velocity as a function of the pion tetraquark tetrahedron fabric cell size, a, is shown below where the maximal velocity of about 0.175 c occurs with the pion tetraquark tetrahedron cell length a of about half the Compton length λ_C. Note that with larger distances between the pion tetraquark tetrahedrons on the vacuum fabric, beyond few λ_C, the electron cannot tunnel to adjacent fabric sites and the electron becomes confined exponentially.

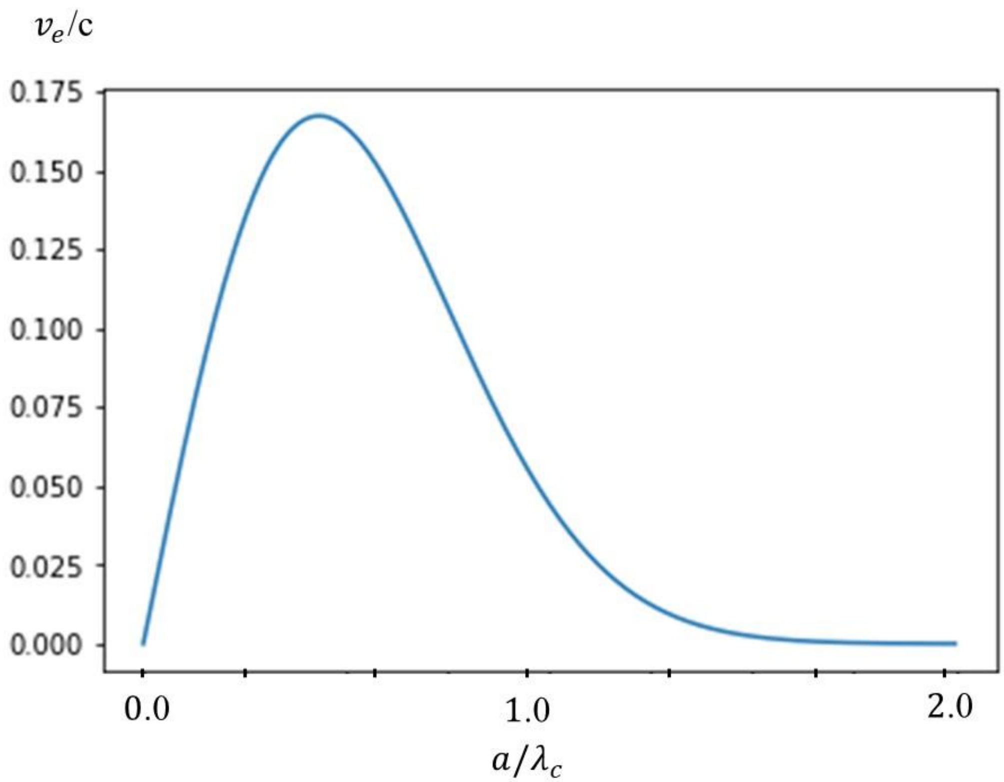

Figure 4 illustrates the electron velocity in the double well potential model tunneling from the first to the second well.

If we assume that an external electromagnetic or gravitational field, or an induced electric field, reduces the potential barrier height, V_0 , see equation 10

$$v_e = \frac{1}{\pi}\sqrt{\frac{8V_0}{m}}\ e^{-\frac{32(V_0 - V_{external})}{3\hbar\omega}} \qquad [\frac{m}{sec}] \tag{10}$$

the electron velocity increases and can reach the speed of light c as proposed by semi-classical electron models for non-point like electron spheres or rings[22—23] as shown in figure 5 below in orange color (the smaller blue curve is with no external field shown in figure 4 above).

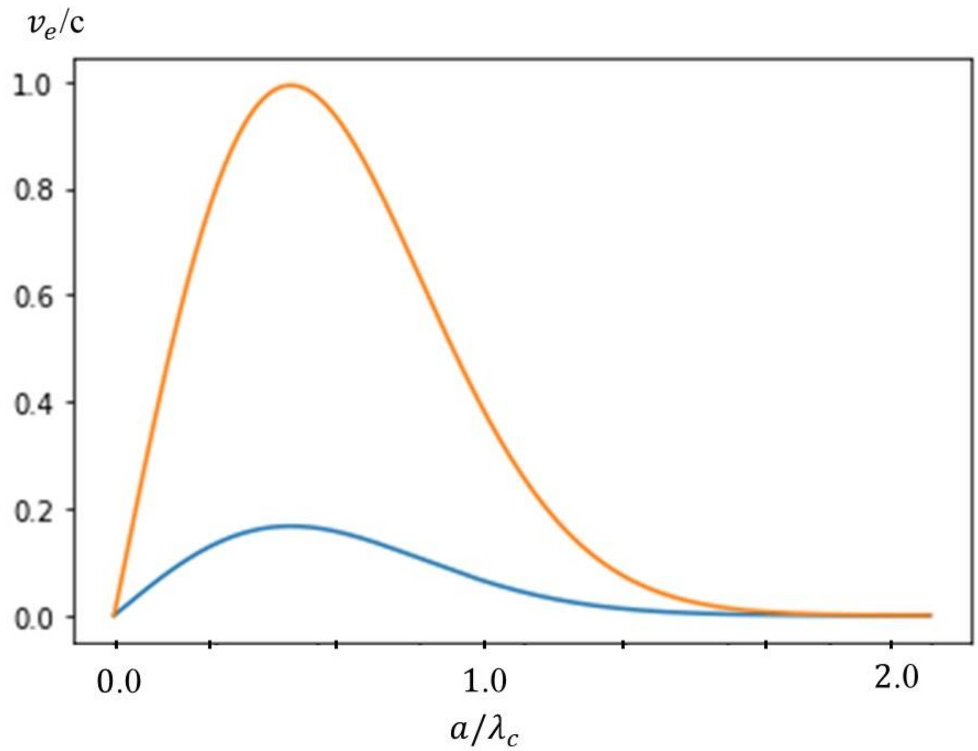

Figure 5 illustrates the electron velocity in the double well potential model with $V_{external} = 0.167\hbar\omega$ (orange) and with no external field (blue).

The distances between the pion tetraquark tetrahedrons in the vacuum fabric, the vacuum fabric density, determine the ability and efficiency of the quark flavor exchange reactions that determine the electrons velocity in the vacuum fabric.

4. The Positron Tetraquark Tetrahedron

The positrons tetraquark tetrahedrons have a positive charge of the u and $\tilde{d}$ quarks instead of the negative charge $\tilde{u}$ and d quarks of the electron tetraquark tetrahedrons as shown below in figures 6 (a-b) for the electrons on the left and for the positrons on the right in figures 6 (c-d). Two positron enantiomers may exist with right and left chirality similar to the electron tetraquark tetrahedron enantiomers.

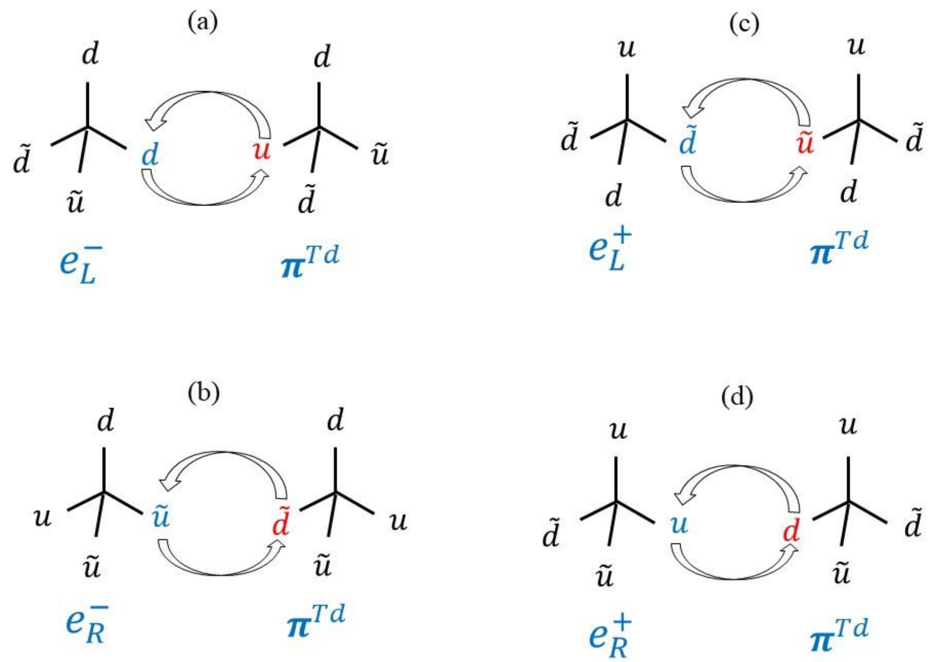

Figure 6 illustrates electron tetraquark tetrahedron enantiomers (a) and (b) and positron tetraquark tetrahedron enantiomers (c) and (d) exchanging quarks with pion tetraquark tetrahedrons with symmetric reactions such that the electrons and positrons transform to pion tetraquark tetrahedrons and vice versa conserving the charge and chiral state.

5. Electron-Positron Annihilation

Electron-positron tetraquarks tetrahedrons annihilation on the pion tetraquark tetrahedron fabric may occur by a collision of an electron tetraquark tetrahedron and a positron tetraquark tetrahedron on the quantum fabric that form two pion tetraquark tetrahedrons that become part of the quantum vacuum pion tetrahedron fabric as shown in equation 14.

$$\tilde{u}d\tilde{d}d(e_L^-) + u\tilde{d}\tilde{u}u(e_R^+) \rightarrow \tilde{u}du\tilde{d}(\pi^{Td}) + \tilde{d}d\tilde{u}u(\pi^{Td}) \tag{14}$$

Hence if an electron tetrahedron in site i on the fabric collide with a positron on adjacent site j, the outcome is that in both sites i and j after the collision there remain two neutral pion tetraquark tetrahedrons, where the electron and positron charges and spins were annihilated and the extra energy of the electron and positron may be transferred to the vacuum pion tetraquark tetrahedron fabric as electromagnetic wave excitations.

6. Summary

We propose a quark theory of the electron and the vacuum where the electron is not an elementary point like and not a single particle. The electron tetraquark tetrahedron is comprised of quarks and antiquarks, and it forms with the vacuum pion tetraquark tetrahedrons fabric a delocalized electron cloud. We propose that the quantum vacuum has a structure formed by massive pion tetraquark tetrahedrons fabric with varying density where the massive pion tetraquark tetrahedrons are made of 50% matter and 50% antimatter particles and hence the fabric is not a regular matter and may be seen as invisible, chargeless and spinless Dirac Sea. We propose that the electron motion occurs via u and d quark flavor exchange tunneling reactions between electron tetraquark tetrahedrons and pion tetraquark tetrahedrons on the vacuum fabric through a double well potential in a first electron chiral state, and the exchanges of $\tilde{u}$ and $\tilde{d}$ antiquark flavors in the second electron chiral state.

References

[1] P. A. M. Dirac, (1928), “The Quantum Theory of the Electron”, https://www.physics.rutgers.edu/grad/601/QM502_2019/Dirac.pdf

[2] Kaplan, I. G., (2019). ”Pauli Exclusion Principle and its theoretical foundation”, https://arxiv.org/pdf/1902.00499

[3] Barut, A.O. and Pavsic, M., (1993), “Dirac's shell model of the electron and the general theory of moving relativistic charged membranes”, https://www.sciencedirect.com/science/article/abs/pii/037026939391136B

[4] Feynman, R., “The Feynman Lectures on Physics, Quantum Mechanics”, https://www.feynmanlectures.caltech.edu/III_toc.html

[5] P. A. M. Dirac, (1928), “Lecture on the Foundation of Quantum Mechanics”, https://mediatheque.lindau-nobel.org/recordings/34222/1965-the-foundations-of-quantum-mechanics

[6] Rom, R., (Apr 2023), “The Quantum Chromodynamics Gas Density Drop and the General Theory of Relativity Ether”, Journal of High Energy Physics, Gravitation and Cosmology, 9, No. 2. https://www.scirp.org/journal/paperinformation.aspx?paperid=124153

[7] Rom, R., (Apr 2023), “Matter Reactors”, Journal of High Energy Physics, Gravitation and Cosmology, 9, No. 2. https://www.scirp.org/journal/paperinformation.aspx?paperid=124154

[8] Rom, R., (Apr, 2024), “Non-Uniform Pion Tetrahedron Aether and Electron Tetrahedron Model”, Journal of High Energy Physics, Gravitation and Cosmology. https://www.scirp.org/journal/paperinformation?paperid=132602

[9] Rom, R., (Jan 2024), “The Pionic Deuterium and the Pion Tetrahedron Vacuum Polarization”, Journal of High Energy Physics, Gravitation and Cosmology, 10, No. 1. https://www.scirp.org/journal/paperinformation?paperid=130928

[10] Rom, R., (May 2024), “QCD’s Low Energy Footprint”, https://vixra.org/abs/2403.0128

[11] Lee, T., (2012), “Vacuum quark condensate, chiral Lagrangian, and Bose-Einstein statistics”, https://arxiv.org/abs/1206.1637

[12] Brodsky, S. B., Shrock, R., (2008), “On Condensates in Strongly Coupled Gauge Theories”, https://arxiv.org/abs/0803.2541

[13] Brodsky, S. B., Roberts, C. D., Shrock, R., Tandy, P.C., (2010), “Essence of the vacuum quark condensate”, https://arxiv.org/abs/1005.4610

[14] Buballa, M., Carignano, S., (2014), “Inhomogeneous chiral condensates”, https://arxiv.org/abs/1406.1367

[15] Byers, N., (1998), “E. Noether’s Discovery of the Deep Connection Between Symmetries and Conservation Laws”, https://arxiv.org/abs/physics/9807044

[16] Burkert, V.D. et al, (2022), “Precision Studies of QCD in the Low Energy Domain of the EIC”, https://www.researchgate.net/publication/365850432_Precision_Studies_of_QCD_in_the_Low_Energy_Domain_of_the_EIC

[17] Paraoanu, G.S., (2014), ”The Quantum Vacuum”, https://arxiv.org/abs/1402.1087

[18] Keenan, R.C., Barger, A.J, Cowie, L.L., (2013) “EVIDENCE FOR A ~300 MEGAPARSEC SCALE UNDER-DENSITY IN THE LOCAL GALAXY DISTRIBUTION”, The Astrophysical Journal, 775:62 (16pp), 2013, September 20.

[19] Banik, I., (Nov 20, 2023), “Do we live in a giant void? It could solve the puzzle of the Universe’s expansion”, https://theconversation.com/do-we-live-in-a-giant-void-it-could-solve-

the-puzzle-of-the-universes-expansion-216687#:~:text=When%20we%20measure%20the%20expansion,area%20with%20below%20average%20density).

[20] Mazurenko, S., Banik, I., Kroupa, P., Haslbauer, M., (Nov 20, 2023), “A simultaneous solution to the Hubble tension and observed bulk flow within 250 h −1 Mpc”, https://arxiv.org/abs/2311.17988

[21] Grabovsky, D, (2021), “The Double Well”, https://web.physics.ucsb.edu/~davidgrabovsky/files-teaching/Double%20Well%20Solutions.pdf

[22] Santos, I. U., (2023), “The zitterbewegung electron puzzle”, https://www.researchgate.net/publication/374257062_The_zitterbewegung_electron_puzzle

[23] Davis, B.S., (2020), “Zitterbewegung and the Charge of an Electron”, https://arxiv.org/abs/2006.16003