Valence Quark-Based Theory of the Quantum Vacuum Structure and Matter

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Abstract: According to the Standard Model (SM) the quantum vacuum is not empty. However, General Relativity (GR) and the SM do not describe the vacuum structure. We propose a valence quark-based theory of the quantum vacuum structure and matter based on pion tetraquarks that fill space with varying density. We assume that the valence quarks and antiquarks, u , d , $\tilde{u}$, $\tilde{d}$ that form the vacuum pion tetraquark tetrahedron lattice are also the building blocks of the protons, neutrons, electrons, and positrons. Motion of particles made of quarks on the vacuum pion tetrahedron lattice is performed by quark exchange reactions by quantum tunneling through a double well potential barrier and motion of massless particles are performed by internal degrees of freedom motion of the pion tetrahedron lattice. Active Galactic Nuclei (AGN) systems may be Carnot engines working between cold BH and hot accretion disk reservoirs. The proposed AGN system Carnot cycle based on the theory of the quantum vacuum and matter structures creates and emits pion tetrahedrons, protons and electrons to space in pulses by the AGN jets that may lead to the observed expansion of the universe.

Keywords: General Relativity (GR), Standard Model (SM), Quantum vacuum, Pion tetrahedrons, Zitterbewegung, Zero-Point-Energy (ZPE), Active Galactic Nuclei (AGN), Supermassive Black Holes (SMBH) and Carnot Engine.

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1. The Quantum Vacuum Structure and the Valence Quarks

According to the standard model (SM), the mass of the elementary particles is due to the Higgs mechanism where a non-zero vacuum expectation value (VEV) spontaneously breaks the chiral symmetry of the otherwise massless particle solution of the Dirac Lagrangian. The SM assumes that the quantum vacuum is not empty but does not tell what is the structure of the vacuum that creates the non-zero VEV and the Mexican hat potential[1-5]. The internal structure and spin of the elementary particles will be studied by the EIC[6]. Paraoanu described the quantum vacuum as an entity endowed with structure, which lies beneath the existential level of real matter[7] and cites Einstein's words - "*There is no such thing as an empty space, i.e. a space without field. Space-time does not claim existence on its own, but only as a structural quality of the field*". In previous papers we described the electron and pion tetrahedron models and various quark exchange reactions of the pion tetrahedrons including $\boldsymbol{\beta}$ decay and quark confinement[8-11].

In this paper we focus on a theory of the quantum vacuum structure filled with pion tetrahedron tetraquark lattice. We note that the vacuum pion tetrahedrons are not ordinary matter since they are composed of 50% antimatter that "annihilates" the other 50% matter, however, the pion tetrahedrons have properties like mass, rotational and vibrational energy and electric dipole. Each lattice site contains a single tetraquark, $u\tilde{d}d\tilde{u}$, composed of two valence quarks and their antiquark pairs and having a tetrahedron structure. There are two pion tetrahedron chiral enantiomers obtained by exchanging the positions of two quarks at the tetrahedron vertices as shown below in line with Dirac/Weyl massless chiral spinors[1-5].

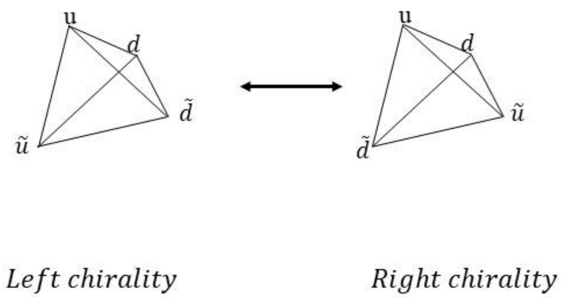

Figure 1 illustrates the two pion tetrahedron enantiomers where the $\tilde{u}$ and $\tilde{d}$ antiquarks exchange positions.

We assume that the pion tetrahedron lattice in empty space may be a simple cubic lattice. However, in the vicinity of a massive star, the pion tetrahedron lattice may have a spherical symmetry with a cell size that changes according to the distance from the star. Each lattice site contains a single pion tetrahedron tetraquark, $u\tilde{d}d\widetilde{u}$, composed of the two valence quarks and their antiquark pairs. The size of the tetrahedron edge may be a fraction of a femtometer while the pion tetrahedron lattice length in free space may be much larger, for example about $5.0 * 10^{-8}$ meter. In extreme gravitational fields, in the vicinity of a black hole for example, the pion tetrahedron lattice cell size may become extremely short, similar to the pion tetrahedron edge size of about $0.5 * 10^{-15}$ meter or less. Far away from any galaxy in the cosmic voids, the pion tetrahedron lattice may be extremely diluted and the lattice cell size may be much larger, ~ $1.0 * 10^{-3}$, meter for example. In the cosmic voids[12-14] the Modified Newton Dynamics (MOND) low acceleration limit, $F = m\,\frac{a^2}{a_0}$, where a << a_0, may be obtained with $a \sim \frac{GM}{r}$ instead of Newton's acceleration $a = \frac{GM}{r^2}$ [9].

We assume that the pion tetrahedrons in each lattice site are massive and respond to gravitational field like a gas in gravitational field with exponential density drop[8]

$$\rho(r) = \rho(r_0) e^{\frac{-GM_s m_\pi (r - r_0)}{r_0{}^2 k_b T}} \qquad (1)$$

The pre-exponent density $\rho(r_0) = \frac{N}{V}$ may be estimated according to the mass of the black hole divided by the mass of a proton $N = \frac{M_{BH}}{M_p}$ divided further by the volume of the black hole Schwarzschild radius r_s cube or the star radius cube. We assume that the maximal density of the pion tetrahedron lattice is obtained when the number of pion tetrahedrons are equal to the number of protons in the star or BH.

$$\rho(r_0) = \frac{N}{V} = \frac{3M_s}{M_p 4\pi r_s^3} \quad \frac{\#\,pions}{m^3} \qquad (2)$$

For the Sagittarius A black hole, the pion tetrahedrons density on its Schwarzschild radius is $6.55 * 10^{32}\ \frac{\#\,pions}{m^3}$ and for the sun on its surface it is $8.431 * 10^{29}\ \frac{\#\,pions}{m^3}$. For a single proton it is $7.799 * 10^{17}\ \frac{\#\,pions}{m^3}$, which is a huge number of pion tetrahedrons but still 6 orders of magnitude smaller than Avogadro's number $6.023 * 10^{23}$.

2. The Electron Model and the Quantum Vacuum Valence Quarks

Electrons in the proposed quantum vacuum structure theory are non-elementary composed particles made of tetraquarks having two configurations we refer to herein as a right chiral $\tilde{u}\,du\tilde{u}$ and a left chiral $\tilde{u}\,dd\tilde{d}$. Adding an electron to the pion tetrahedron lattice is done by replacing one pion tetrahedron with one of the two chiral electron tetrahedrons and then using a double well potential Hamiltonian[15] that represents an exchange of quarks between the electron and the pion tetrahedron on adjacent sites that transform the chiral electron tetrahedron to a pion tetrahedron and vice versa as shown in equation 1 below for a left chiral electron where the u *and* d quarks are exchanged as shown in figure 2 and equations 1 and 2 below.

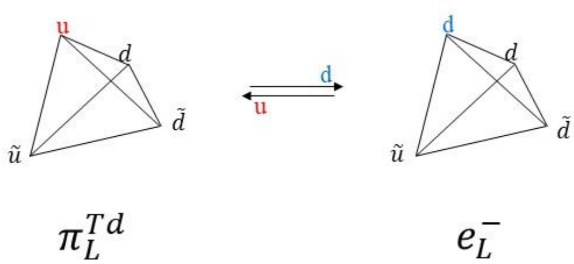

Figure 2 illustrates an electron and a pion tetrahedron where a single quark flavor is exchanged (u and d).

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

In the case of the right chiral electron the $\tilde{u}$ *and* $\tilde{d}$ antiquarks are exchanged, and the exchange reaction equation is

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

Since the quark exchange reactions are symmetric, the reactants on the left-hand-side and the products on the right-hand-side are identical, the usage of the double well potential Hamiltonian is justified[15].

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

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 barrier height, $V_0 = m\,\lambda\,a^4$. Based on Dirac equation zitterbewegung force free trembling motion, we assume that in free space the potential barrier height $V_0 = \hbar\boldsymbol{\omega} = 2m_e c^2$, and hence the frequency $\omega = \frac{2m_e c^2}{\hbar}$ is equal to Dirac's equation zitterbewegung[16]. Accordingly, the approximate 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 and pion tetrahedron quark flavor exchange reaction in lattice sites i and j in the ground state. The quark exchange reaction and the double well potential is replicated between all adjacent lattice sites and the electron motion in the ground state is hence by quantum tunneling through the potential barrier V_0, which is twice the electron rest mass energy and represents the threshold for electron-positron pair production. Note that the electron tetraquark on both sides of the double well is identical and hence the electron configuration ($\widetilde{u}\,dd\widetilde{d}$ or $\widetilde{u}\,du\widetilde{u}$) is dynamically conserved while the quark exchanges occur with the zitterbewegung frequency.

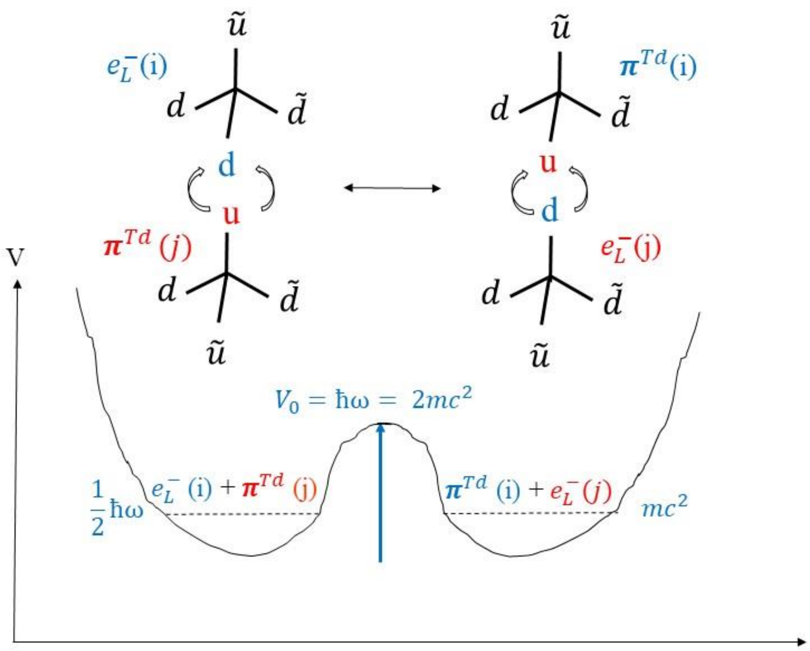

Figure 3 illustrates the double well potential model for the electron and pion tetrahedron quark flavor exchange reaction in lattice sites i and j in the ground state. Note that the potential barrier V_0 is twice the electron rest mass energy and represents the threshold for electron-positron pair production.

The tunneling probability, T, from the first to the second potential well in the ground state through the potential barrier is[15]

$$T = e^{-\frac{8\,ma^3\sqrt{2\lambda}}{3\hbar}} = e^{-\frac{32V_0}{3\hbar\omega}} \tag{4}$$

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

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

We may assume that the barrier height potential V_0 may vary in space according to the gravitational field for example and that $2m_ec^2$ is its absolute minimal value and accordingly we may determine the electron velocity in space on the pion tetrahedron lattice. The velocity of the electron tetrahedron from site i to j due to the flavor exchange wave is calculated by the distance between the sites, a, divided by the time period, τ, and multiplied by the tunneling probability in the ground state T.

$$v_e = \frac{a}{\tau}\mathrm{T} = \frac{a\omega}{2\pi} e^{-\frac{32V_0}{3\hbar\omega}} \tag{6}$$

Since the electron velocity is limited by the speed of light, we get the following expression for the tunneling velocity from site to site.

$$\frac{a\omega}{2\pi} = c\, e^{\frac{32}{3}} \tag{7}$$

And an expression for the electron velocity.

$$\frac{v_e}{c} = e^{-\frac{32}{3}(\frac{V_0}{\hbar\omega} - 1)} \tag{8}$$

In the case that $V_0 = \hbar\boldsymbol{\omega}$ the electron velocity is maximal and equals to the speed of light, this means that in reality V_0 must be bigger than $\hbar\omega$.

The electron does not follow a classical trajectory, quarks are exchanged between the pion tetrahedron sites by tunneling through a potential barrier and effectively the motion of the electron creates a delocalized cloud. We assume that in some small Compton length range, $V_0 = \hbar\boldsymbol{\omega}$, and the electron speed may be equal to the speed of light as in Dirac's equation zitterbewegung and semi-classical electron models[16--17]. Out of this small region that may be in a shape of a ring or a torus, $V_0 > \hbar\boldsymbol{\omega}$, the electron speed is smaller than the speed of light. The double well potential barrier height for the quark flavor exchange in lattice sites i and j may be a function of the exchanged quark states $V_0\ (d_i, u_j)$. The pion tetrahedron quarks may rotate or vibrate with long range correlation creating local electric and magnetic fields since the quarks are electrically charged. The double well potential with $\frac{V_0}{\hbar\omega} = 1.0$ and with $\frac{V_0}{\hbar\omega} = 2.0$ are shown below. With a larger potential barrier V_0 the wells are steeper, the tunneling probability through the barriers is smaller, the quark flavor exchange wave propagation is slower and the electron ground state wavefunction is more localized inside the well.

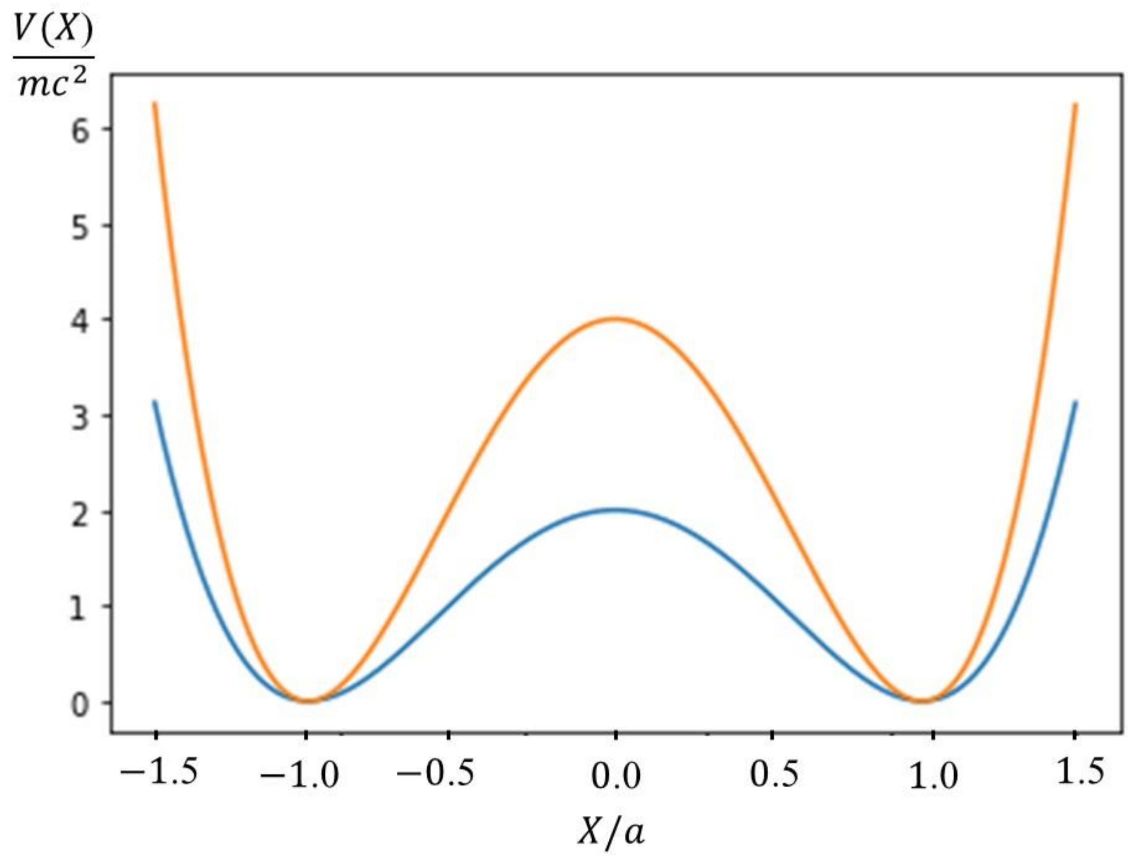

Figure 4 illustrates the double well potential with two values of the barrier height $V_0 = 2m_e c^2$ and $V_0 = 4m_e c^2$ with a = $5.2045 * 10^{-8}\ m.$

The frequency ω times the pion tetrahedron lattice cell length a is a constant (equation 7 above)

$$\omega\, a = 2\pi c e^{\left(\frac{32}{3}\right)} = 8.0811 * 10^{13} \qquad (9)$$

Using the zitterbewegung frequency, in the Compton region where the potential barrier height is minimal $V_0 = \hbar\boldsymbol{\omega}$, we can calculate the pion tetrahedron lattice cell length in free space

$$a = \frac{8.0811 * 10^{13}}{\omega} = \frac{\hbar\, 8.0811 * 10^{13}}{2 m_e c^2} \text{ meter} \qquad (10)$$

$$a = \frac{8.0811 * 10^{13}}{1.5527 * 10^{21}} = 5.2045 * 10^{-8} \text{ meter} \qquad (11)$$

Note that with $V_0 = \hbar\boldsymbol{\omega}$, and the zitterbewegung frequency $\omega = \frac{2 m_e c^2}{\hbar}$, the barrier height is $V_0 = 2 m_e c^2$, which is the threshold for production of an electron-positron pair. The potential parameter λ is given by $\lambda = \frac{V_0}{m_e\, a^4} = \frac{2\, c^2}{a^4} = 2.4498 * 10^{46} \frac{1}{m^2 sec^2}$

The first order correction to the ground state energy of $E_0^{(0)} = \frac{1}{2}\hbar\boldsymbol{\omega}$ in the double well is[15]

$$E_0^{(1)} = \frac{3\hbar^2}{32 m_e a^2} = 2.637 * 10^{-6}\ eV \qquad (12)$$

The electron mass may be measured with high precision[18] where small deviations due to the time periodic variable interaction with the vacuum pion tetrahedron density may be measurable[11].

Assuming that the mass of the pion tetrahedron is about 6 orders of magnitude smaller than the electron, the pion tetrahedron density in free space may be estimated roughly.

$$\rho_{pion\ tetrahedron} = \frac{10^{-6}\, m_e}{(5.204 * 10^{-8})^3} = 6.46 * 10^{-15} \ \frac{k_g}{m^3} \qquad (13)$$

The estimated density of the universe is $9.9 * 10^{-27} \frac{k_g}{m^3}$, which is equivalent to 5.9 protons in meter cube. Only 4.7% of the total density is due to visible matter which is about $4.33 * 10^{51} k_g$. The estimated volume of the visible universe is $9.322 * 10^{78} m^3$. If we assume that the pion tetrahedron density in the universe is uniform its mass will be about $6.023 * 10^{64}\ k_g$, 13 orders of magnitude larger than the visible mass. However, we assume that the pion tetrahedron density is denser close to matter particles and is extremely diluted far from matter for example in the cosmic web voids. The pion tetrahedron mass in the universe is probably much smaller than $6.023 * 10^{64}$ k_g, still, due to the huge volume of the universe, the pion tetrahedron mass should not be neglected.

3. The $\boldsymbol{\beta}$ Decay and the Electron Model

We assumed that electrons are composed of tetraquarks, and we did not attempt to provide a proof for the electron model[8-11]. Here we want to show that the $\boldsymbol{\beta}$ rays, which were discovered in 1899 by Ernest Rutherford, give a significant support for the proposed quark content of the electron tetrahedron model. In 1900, Becquerel measured the mass-to-charge ratio (m/e) for radioactive $\boldsymbol{\beta}$ particle emission and found that m/e ratio for $\boldsymbol{\beta}$ particles is the same as Thomson's cathode ray electrons and suggested that $\boldsymbol{\beta}$ rays are electrons[19-20]. At that time, protons and neutrons and their internal structure were not known and the question how an electron is emitted from a nucleus made of protons and neutrons that contains quarks and gluons only[6] could not be asked. We propose to write down a quark based $\boldsymbol{\beta}$ decay equation and get an expression for the electron that propagate on the pion tetrahedron lattice (assuming that the valence quarks and antiquarks are conserved).

$$udd\ (n) + u\tilde{d}d\tilde{u}\ (\pi^{Td}) \rightarrow udu\ (p^{+}) + \tilde{u}\ d\ \tilde{d}d\ (e_L^{-}) + \tilde{\nu}_{\sigma} \qquad (14)$$

Note that the $\boldsymbol{\beta}$ decay according to equation 14 describes a second order kinetic reaction where a collision between a neutron and a pion tetrahedron triggers the quark exchange reaction. The second order kinetics classification is important since if the density of the pion tetrahedrons is reduced, for example in the cosmic voids, the rate of the $\boldsymbol{\beta}$ decay will be reduced too. Hence the $\boldsymbol{\beta}$ decay rection rate is not a first order kinetic constant and it should depend on the pion tetrahedrons density that drops like the atmospheric density drops away from earth surface[8].

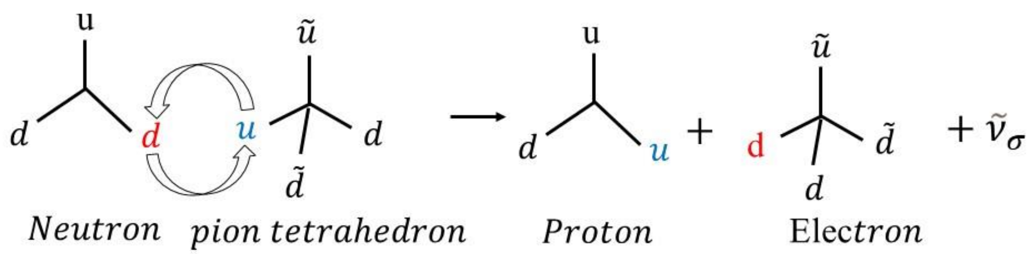

Figure 5 illustrates the $\boldsymbol{\beta}$ decay as a quark exchange reaction between a neutron and a pion tetrahedron as a second order kinetics reaction.

The electron tetrahedron $\tilde{u}\, d\tilde{d}d\, (\, e_L^-)$ and the anti-neutrino $\tilde{\nu}_\sigma$ are energetic spin half fermions that propagate on the pion tetrahedron lattice. The electron tetrahedron propagates via quark exchange reactions that occur by tunneling through the double well potential barrier while the anti-neutrino propagation may be an internal motion of the pion tetrahedrons degrees of freedom in each lattice site, a vibration or rotation waves that propagate in almost the speed of light on the pion tetrahedron lattice.

Note that the second configuration right chiral electron, $d\tilde{u}\, u\tilde{u}$, described above in equation 2, is not obtained by the $\boldsymbol{\beta}$ decay according to equation 14, which means that the $\boldsymbol{\beta}$ ray electrons are created with chirality as observed experimentally by C. S. Wu in 1957[19-20]. The proposed electron tetrahedron model made of tetraquarks and the $\boldsymbol{\beta}$ decay quark equation 14 with the assumed quark conservation rule provides a reaction mechanism for the $\boldsymbol{\beta}$ decay process that explains the chirality of the emitted electrons and also predicts a second order kinetics and a dependence on the gravitational field of the decay rate that may be observed[8].

The β^+ decay transform a proton to a neutron and emits a positron with the opposite chirality comparing to the electron emitted in the β^- decay. The β^+ decay is a third order kinetic reaction triggered by a neutrino and a pion tetrahedron and it conserve the valence quark numbers that are only rearranged differently in both reactions.

$$udu\ (p^+) + u\tilde{d}d\tilde{u}\ (\pi^{Td}) + \nu_\sigma \rightarrow udd\ (n) + u\tilde{d}u\tilde{u}\ (e_R^+) \qquad (15)$$

4. The Positron Model and the Quantum Vacuum

We assume that positrons are tetraquark tetrahedrons like the electron tetrahedrons but having a $u\,\tilde{d}$ quark pair with a plus charge instead of the $\tilde{u}\,d$ quark pair with a negative charge for the electron as shown below in figures 6 (a-b) for the electrons on the left and figures 6 (c-d) for the positrons on the right. Two positron configurations can be described with right and left chirality like the electrons and have additional $d\,\tilde{d}$ or $\tilde{u}\,u$ quark pairs as shown below in figures 6 (c-d) on the right.

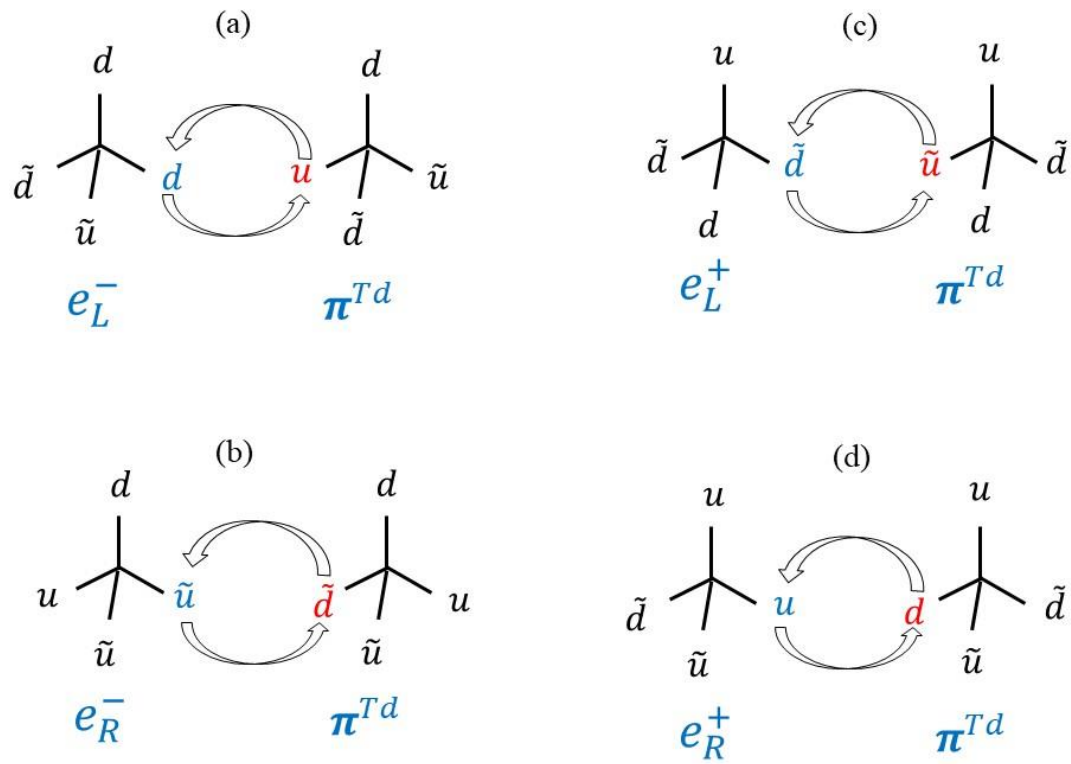

Figure 6 illustrates electron tetrahedrons (a) and (b) and positron tetrahedrons (c) and (d) exchanging quarks with pion tetrahedrons with symmetric reactions such that the electrons and positrons transform to pion tetrahedrons and vice versa in each exchange reaction.

5. Electron-Positron Condensation

Electron-positron annihilation according to the theory of the quantum vacuum structure is a condensation of an electron tetrahedron and a positron tetrahedron into two pion tetrahedrons that become part of the quantum vacuum structure lattice as shown in equation 16 below.

$$\tilde{u}d\tilde{d}d(e_L^-) + u\tilde{d}\tilde{u}u(e_R^+) \rightarrow \tilde{u}du\tilde{d}(\pi^{Td}) + \tilde{d}d\tilde{u}u\,(\pi^{Td}) \qquad (16)$$

Hence if an electron tetrahedron in site i on the lattice collide with a positron on site j on the lattice the outcome is that in both sites i and j after the collision will become two pion tetrahedrons and the electron and positron are annihilated and energy is transferred to the pion tetrahedron lattice as excitations that propagate in the lattice as two electromagnetic waves.

6. Electron Pairs and Pauli Exclusion Principle

An electron-electron pair may be created by forming a pion tetrahedron that acts a QCD glue as shown in equation 17 below. The chirality/spin of the pair is opposite creating a Cooper pair according to Bardeen-Cooper-Schrieffer (BCS) superconductivity theory[21].

$$\tilde{u}d\tilde{d}d(\,e_L^-) + \,\tilde{u}d\tilde{u}u(\,e_R^-) \;\rightarrow\; \tilde{u}d\tilde{d}d\tilde{u}u\,\tilde{u}d\big(e - e_{\downarrow\uparrow}^{pair}\,\big) \qquad (17)$$

According to BCS theory the electron pairing interaction is mediated by phonons, the motion of the solid-state lattice ions, that creates the attraction between the electron pairs. Here we suggest that the pion tetrahedron acts like a QCD glue connecting the electron pairs in addition to the contribution of the observed lattice phonons, e.g. the isotopic effect. Hence, without phonons the pion tetrahedron interaction is too small and is not strong enough to bind the electron pair in a solid.

We propose further that the electron-electron pair interaction described in equation 17 via the pion tetrahedron QCD glue may be the underlying electron pair attraction mechanism in chemical bonds in atoms and molecules where the pion tetrahedron lattice is denser. When two electron tetrahedrons with opposite chirality collide in site i and j in the dense pion tetrahedron lattice, they are attracted to each other by the formation of the pion tetrahedron QCD glue and they will continue a correlated pair motion on the dense pion tetrahedron lattice. The attraction is a pair attraction, a third electron cannot correlate similarly with the electron pair and this mechanism may be the underlying mechanism for the Pauli exclusion principle[22].

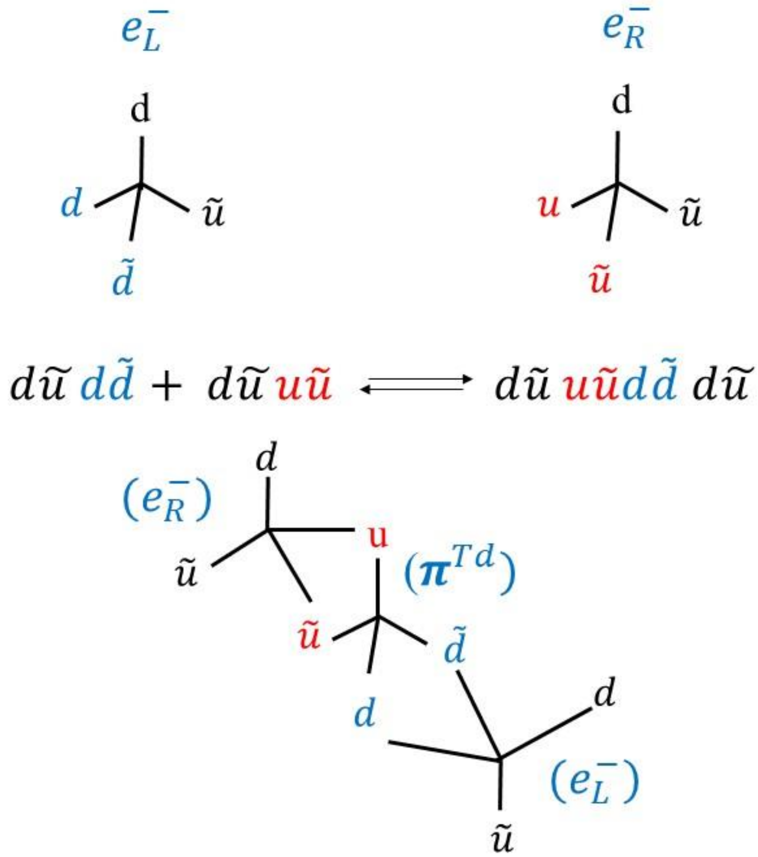

Figure 7 illustrates electron pairing mechanism forming a pion tetrahedron that acts like a QCD glue

7. The Proton Model and the Quantum Vacuum Valence Quarks

A proton on site i and a pion tetrahedron on site j may exchange three quarks according to equation 18(a-b) below where the proton with left or right chirality is transformed to a pion tetrahedron and vice versa. The quark structure and chirality are conserved in both reactions.

$$uduu\tilde{u}\ (p_R^+) + u\tilde{d}d\tilde{u}\,(\pi^{Td}) \rightarrow ud\tilde{d}\tilde{u}\,(\pi^{Td}) + uduu\tilde{u}\,(p_R^+) \qquad (18a)$$

$$udud\tilde{d}\ (p_L^+) + ud\tilde{d}\tilde{u}\,(\pi^{Td}) \rightarrow ud\tilde{u}\,\tilde{d}(\pi^{Td}) + udud\tilde{d}\,(p_L^+) \qquad (18b)$$

Note that the reactions are symmetric and may be modeled with a double well potential similar to the electron and pion tetrahedron above, however, the potential barrier is higher now, $2m_pc^2$.

Similar quark exchange reaction can be written for a neutron and the motion of the matter particles, electrons, positrons, protons and neutrons on the proposed vacuum pion tetrahedron lattice is performed by quark exchange reactions between lattice sites that occur with quantum tunneling through a potential barrier. Note that the decomposition of the spin of the proton has been the subject of tremendous interest since the discovery that the intrinsic spin carried by quarks was only about $\lesssim 10\% - 30\%$ of the proton's spin[23]. We propose here that the proton structure includes a $d\tilde{d}$ or a $u\tilde{u}$ mesons as shown below that determines the proton chirality and contribute energy and spin to the proton.

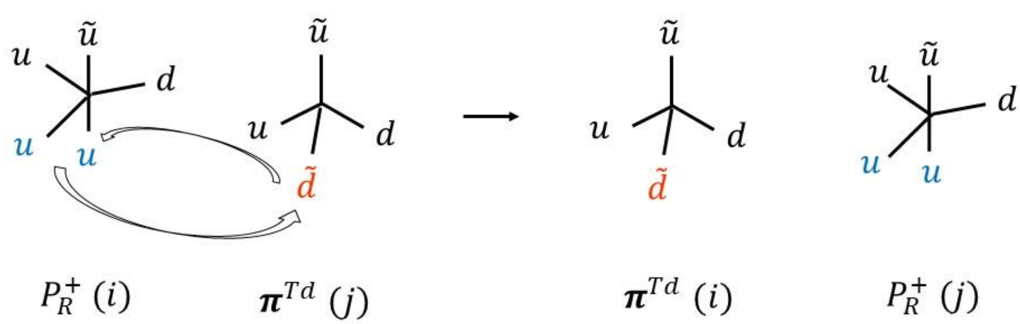

Figure 8 illustrates a proton and a pion tetrahedron quark exchange reaction transforming the proton to a pion tetrahedron and vice versa on the vacuum lattice sites i and j. Note that the right chiral proton structure includes a $u\tilde{u}$ meson.

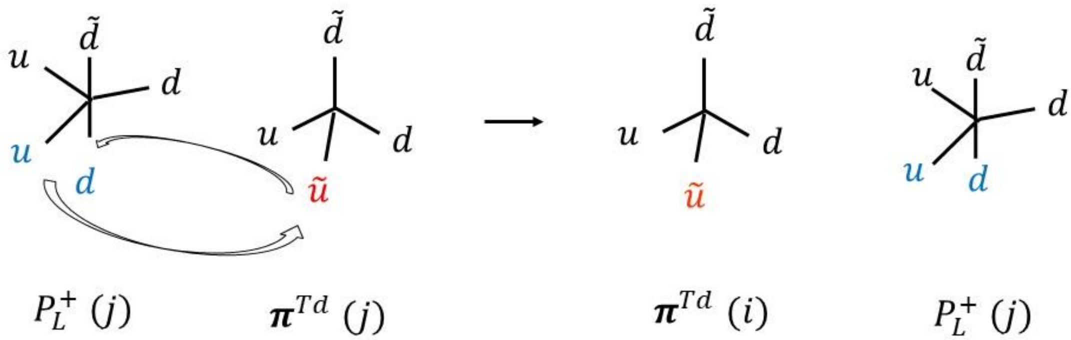

Figure 9 illustrates a proton and a pion tetrahedron quark exchange reaction transforming the proton to a pion tetrahedron and vice versa on the vacuum lattice sites i and j. Note that the left chiral proton structure includes a $d\tilde{d}$ meson.

8. The Pion Tetrahedron Nuclear Glue

The pion tetrahedrons may act as a QCD nuclear glue between a proton and neutron in a deuterium nucleus for example as illustrated in figure 10 and 11 below. The pion tetrahedron allows a double quark exchange between the two hadrons that transform the proton to a neutron and vice versa.

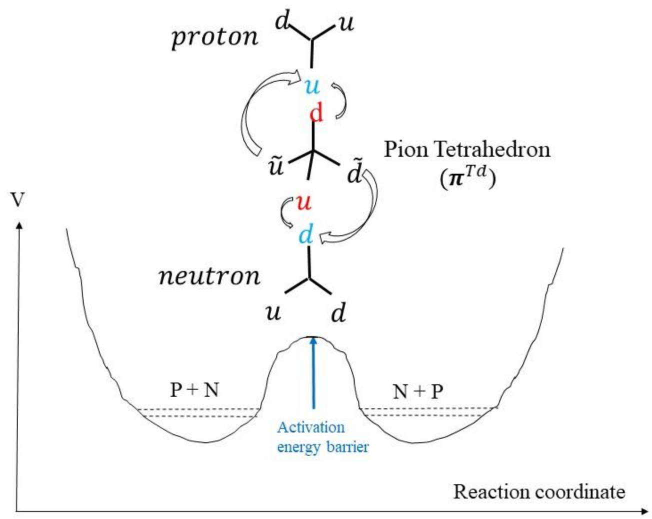

Figure 10 illustrates a proton and a neutron exchanging quarks with a pion tetrahedrons that acts like a QCD glue. Since the quark exchange reaction is symmetric transforming the proton to a neutron and vice versa, a double well potential is created.

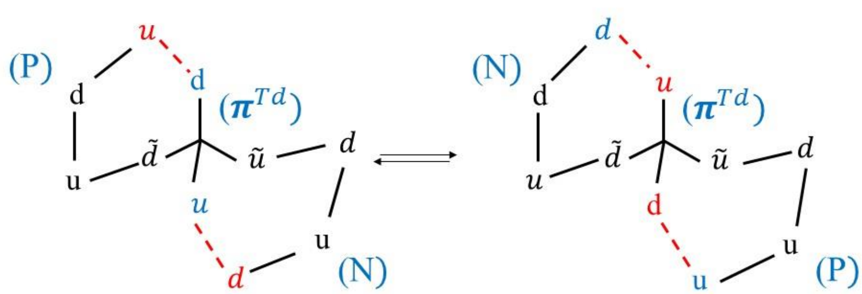

Figure 11 illustrates a proton and a neutron exchanging quarks with a pion tetrahedrons that acts like a QCD glue that provides the quarks for the double exchange reaction.

9. The Pion Tetrahedrons and the AGN Carnot Engine

We assume that matter and antimatter may be separated on the event horizon of black holes (BH) according to Hawking radiation process[24]. Due to the high density of the pion tetrahedron lattice close to the BH event horizon, the distance between the pion tetrahedrons may become less than a femtometer and then a transition state complex of two or even four pions may be created and next be separated into matter and antimatter hadrons. The matter hadrons are emitted to space and the antimatter hadrons remain trapped under the horizon of the black hole according to Hawking radiation. Equation 19a-d below show how neutrons, protons, deuteriums and electrons may be created from two and four pion tetrahedrons.

$$2\, u\tilde{d}d\widetilde{u} \rightarrow \; udd\tilde{u}u(n) \; + \; \tilde{d}\widetilde{u}\,\tilde{d}(\tilde{n}) \qquad (19a)$$

$$2\, u\tilde{d}d\widetilde{u} \rightarrow \; udu\tilde{d}d(p) \; + \; \tilde{d}\widetilde{u}\,\tilde{u}(\tilde{p}) \qquad (19b)$$

$$4\, u\tilde{d}d\widetilde{u}\, d \; \rightarrow \; udd\tilde{d}d\, uudu\widetilde{u}\,(deuteron) + \; \tilde{d}\widetilde{u}\,\tilde{d}\tilde{u}\tilde{d}\widetilde{u}\,(\,antideutron) \quad (19c)$$

Next, neutrons may collide with pion tetrahedrons and split into protons, electrons and anti-neutrinos via the second order kinetics $\boldsymbol{\beta}$ decay -

$$udd\tilde{u}u\,(n) + u\tilde{d}d\widetilde{u}\,(\pi^{Td}) \rightarrow udu\tilde{u}u\,(\,p^{+}) + \widetilde{u}\,d\,\tilde{d}d\,(\,e_L^{-}) + \; \tilde{\nu}_{\sigma} \qquad (19d)$$

Note that according to Corley and Jacobson[25], pion tetrahedrons may be exponentially duplicated in BH ergoregions that act as a laser cavity duplicating bosons. Next the duplicated pions may split according to equations 19a-d and emitted to space by relativistic jets[26] in pulses, where the Supermassive BH (SMBH) Active Galactic Nuclei (AGN) system may act as a Carnot engine working between cold and hot reservoirs[27]. The cold reservoir is the BH ergoregion, and the hot reservoir is the AGN accretion disk. Pion tetrahedrons and matter particles may be emitted to space by the AGN relativistic jets with Carnot engine pulses with a mass gain extracted from the SMBH spin mass-energy[28].

The AGN system Carnot cycle is described below in figure 12 in a typical four step pressure-volume (P-V) diagram. The work that the AGN system does that can be transformed to mass-energy emitted to space by the AGN jets is given by the integral $W = \int PdV$. The proposed Carnot cycle is based on the valence quarks-based theory of the quantum vacuum structure and matter as described below. The first step (I) is hot protons and electrons compression in the AGN accretion disk; the second step (II) is the pion tetrahedron lattice compression in the BH ergosphere that may reach the maximal pressure limit where the distance between the pion tetrahedrons in the lattice is equal to the pion tetrahedron length size (about 0.5 or less femtometers); the third step (III) is an exponential duplication of the pion tetrahedrons in the ergosphere cavity according to Corley and Jacobson BH laser effect[25] and the emission of pion tetrahedrons, protons and electrons to space in the AGN jets from the BH event horizon according to Hawking radiation process and equations 19a-d above that occur at the peak pressure; the fourth step (IV) that completes the Carnot cycle is expansion of the pion tetrahedron lattice in the ergosphere to its initial state P-V values. The proposed Carnot cycle produces pion tetrahedrons, protons and electrons and emits them to space in pulses in the AGN jets in step III of the Carnot cycle. Millions of such AGN Carnot engines fill space with additional pion tetrahedrons that expand the quantum vacuum lattice and with additional protons and electrons that can form new stars and galaxies.

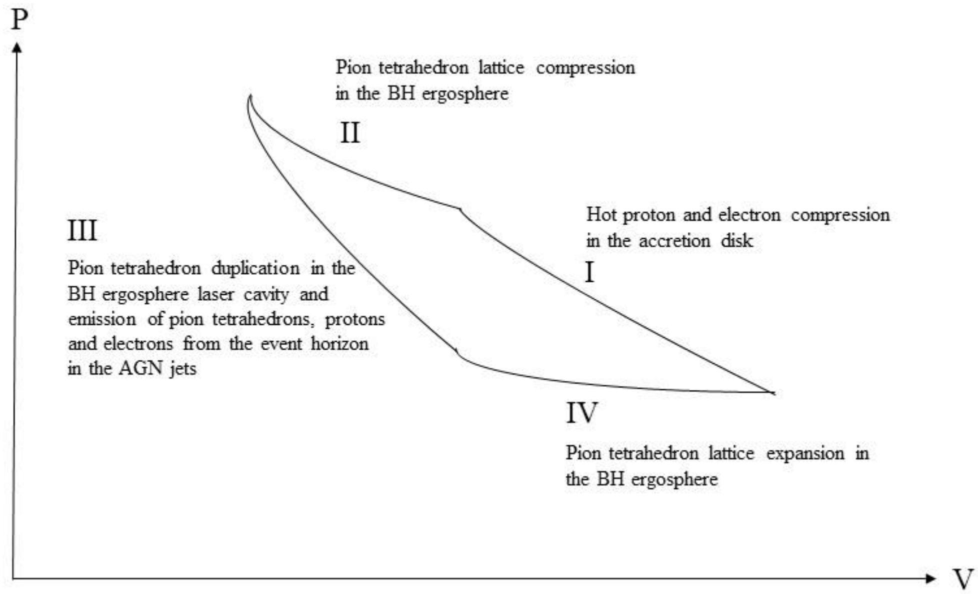

Figure 12 illustrates the four step AGN Carnot engine in a P-V diagram based on the valence quark-based theory of the quantum vacuum structure and matter. Creation and emission of pion tetrahedrons, protons and electrons occur in step III of the proposed Carnot cycle at peak pressure.

10. Summary

According to the theory of the quantum vacuum and matter structures, pion tetrahedron tetraquarks fill space with varying density that depends on the matter included in each space region. The pion tetrahedron lattice allows propagation of massive particles, electrons, positrons, protons and neutrons via rapid quark exchange reactions with the zitterbewegung frequency, and massless particles via vibrations and rotations of the pion tetrahedron lattice with no quark exchanges. The theory of the quantum vacuum structure assumes that the valence quarks and antiquarks, $u, d, \tilde{u}, \tilde{d}$ are the building blocks of the universe and that other stable and unstable particles are comprised from the valence quarks building blocks. The Zitterbewegung force free trembling motion, the Zero-Point-Energy (ZPE) electromagnetic field fluctuations, the $\boldsymbol{\beta}$ decay and high-precision measurements of the electron mass, may prove the proposed valence quark-based theory of the quantum vacuum structure and matter. Finally, an AGN system Carnot cycle is proposed based on the valence quarks-based theory of the quantum vacuum structure and matter, where in step III of the Carnot cycle at peak pressure, pion tetrahedrons, protons and electrons are created and emitted to space in pulses by AGN jets that may lead to the observed expansion of the universe.

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