Cracking the Enigma of Neutrino

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Abstract

Neutrinos, which have been known as elusive ghost-particles, are electrically neutral coming out only in weak interactions, and eccentrically only left-handed neutrinos have been observed. More surprisingly, it has been known that flavors of neutrinos, such as electron, muon, and tau neutrinos, are changed in their propagations, which is known as neutrino oscillation. The peculiarities of neutrinos such as parity violation in weak interaction and neutrino flavor oscillation are reviewed whether those unconventional characters of neutrinos should be accepted just because of the seemingly undeniable physical evidences in phenomenology. For those eccentric neutrino properties in weak interaction, alternatively but surely we can find comprehensive explanations in 4-D complex space.

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Introduction

The elementary particle called neutrino is involved only in weak interaction, in which W or Z boson mediates the interaction in such short range inside the nucleus. Moreover, In spite of the common expectation that is fairness used to be in natural phenomena, only left-handed neutrinos have been observed (Wu and al. 1957), which is the parity violation in weak interaction. However, neutrino has even more unconventional property than the parity violation, which is neutrino oscillation. It has been known that neutrinos have three flavors, such as electron, muon, and tau neutrinos, and antineutrinos corresponding to each of them. Interestingly, it has been known that the flavors of neutrinos are changed to other flavors when they travel, which is the neutrino oscillation (SLAC, Learned 2015, Kajita 2010, SNO Collaboration 2016, Neutrino Research).

Since Wolfgang Pauli postulated the existence of neutrino in 1930, it took 26 years to confirm the existence of neutrino (Cowan and al. 1956). The detection of neutrinos is so difficult in experiments; nevertheless, many experimental researches have been conducted in the world to investigate neutrinos, such as solar neutrinos, cosmic neutrinos, geoneutrinos, etc., especially for neutrino oscillation (Katori 2022, Neutrino Science 2023).

In the neutrino oscillation, the flavor of neutrino, such as electron, muon, or tau neutrino, is a mixture of mass eigenstates or superposed mass eigenstate; the superposed mass eigenstate is oscillating in the way of neutrino propagation and the neutrino flavor is changed. For example, if an electron neutrino is created, the neutrino flavor in the mixed mass eigenstate is electron neutrino, but the mixed mass eigenstate is changed to other neutrino flavors when it propagates through space, and the flavor of neutrino is coming back to electron neutrino again.

In the theory of neutrino oscillation, each flavor of neutrinos has to have non-zero mass, and the mass should be different from other masses for the oscillation of neutrino flavors. Then, it is natural that we can ask how the neutrino flavors such as ν_e, ν_μ, and ν_τ can be identified in the middle of propagation, in which the transition of neutrino flavors should be continuous and smooth from one flavor to another in time and space. Then, it is questionable how we can understand the weak interaction: charged-current (CC) interaction producing a neutrino flavor, which is one of ν_e, ν_μ, and ν_τ, and the charged lepton corresponding to the neutrino such as e, μ, or τ respectively, and neutral-current (NC) interaction in which the neutrino flavor cannot be identified. For a possible state in the middle of transition from one flavor of neutrino to another, which can not be identified with the CC neutrino interaction, it is questionable whether the possible state in the middle of transition is a kind of neutrino or it can participate in NC neutrino interaction or not.

The question of physical reality, which has been asked in the theory of quantum physics since 1920s, seems to be still embedded in the theory of neutrino oscillation with more complex form than in conventional standard interpretation of quantum physics. However, we need to review whether the mixed mass eigenstates in quantum physics can be used for the theory of neutrino oscillation or not. In other words, we need to confirm whether the theory of neutrino oscillation can be compatible with the conventional interpretation of quantum physics, which is so-called Copenhagen interpretation.

We already suggested that neutrino is not a massive particle but the wave motion of vacuum particles in longitudinal mode in 4-D complex space. In addition, we explained that the parity violation in weak interaction should not be true with a model of W boson (Kim 1998). Here once again, with the model of W boson in weak interaction and the model of neutrino, which is a bundle of longitudinal vacuum-string waves, we can find comprehensive explanations for those even weird properties of neutrino all together. Let's start with reviewing the physical reality of quantum physics.

Physical Reality in Quantum Physics

It seems that the interpretation of quantum theory has not been settled yet completely. Although the Copenhagen interpretation has been prevailing consensus in physics, there have been many questions still being discussed (Siegfried, Dimitropoulos 2022, Wiki_QuantumReality, and many more elsewhere), such as "Schrodinger's Cat", "Einstein's Moon", "wave function collapse", and other interpretations too, such as "many worlds interpretation" (Crease 2019, Gribbin 2020).

However, we can find the answers for those fundamental questions in 4-D complex space with ontological interpretation of physical reality (Kim 1997, Kim 2017): physical objects are always interacting with vacuum particles in imaginary subspace (physical vacuum space), and the interactions are realized in phenomena (physics in real subspace) with positive energies, such as lights, positive mass particles, etc., generated and/or created through the interferences and/or interactions between the distributions of vacuum particles for the physical objects or simply interacting of vacuum particles.

The wave function, which is the mathematical description of quantum state in quantum physics, is representing the distribution of vacuum particles in physical vacuum space; however, the wave function itself is not representing the physical object directly since the physical interactions or interferences are in the physical vacuum space. Once the wave function $\psi\left(\bar{x},t\right)$ is absolute squared as $\text{Prob} \sim \psi^{*}\psi$, it is realized as the probability density in physics because the wave function is not for the physical object itself but for the distribution of vacuum particles that actually participates in physical interactions and this is the reason that the probability nature appears in quantum physics.

Nature has unique intrinsic statistical property, and natural phenomena cannot be explained completely only with phenomenological descriptions. The quantum theory can be compared with classical wave theory, but the physical reality is not shown directly as in the classical theory. Therefore, in quantum physics the quantum state itself does not link directly to the physical object. For example, in a double-slit experiment of high-energy electron beam, we cannot trace down all the processes, interactions or interferences for each electron, but we can find an interference pattern at the end.

Let's say, in quantum physics describing a physical system, where the status of system is superposed with many quantum states, which is represented with a linear combination of the quantum states. If each quantum state represents a status of the physical system, it is natural to ask following questions: for example, in the "Schrodinger's Cat", the status of cat is alive and dead simultaneously, and only through observations it is determined whether the cat is alive or dead. Then, the question is how these two exclusive statuses, alive and dead, are possible at the same time. Then, another extreme statement or further interpretation is added as following: physical reality exists only with measurements or through observations. For this kind of awkward and extreme interpretation, Albert Einstein asked whether there is no moon or not if he doesn't look at the moon. However, there is another drastic interpretation of quantum physics in many-worlds theory (Gribbin 2020), in which if each quantum state represents physical reality, for example, in the "Schrodinger's Cat", and if the cat is observed alive, the cat is alive in our world; however, the cat is dead in another world that we cannot connect to.

In 4-D complex space, the quantum state is the statistical representation of vacuum particles interacting with physical objects, not the physical object itself. The origin of physical interactions, such as gravitational interaction, electromagnetic interaction, and so on, can be found with the first principle given in the space. The physical reality is realized not from each quantum state but with the probability through measurements or physical interactions.

Parity Violation in Weak Interaction

It is obvious that natural phenomenon itself should not be different with the coordinate systems used in physics: for example, physics should be invariant in a coordinate system (x, y, z) and in another system $(-x, -y, -z)$, which is a space inversion of Cartesian coordinates in 3-D. Parity transformation is the coordinate transformation among coordinate systems in which physics is supposed to be invariant. In quantum mechanics the wave function has two eigenvalues ($+1$ and -1) for the parity operation as $P|\psi\rangle = \pm|\psi\rangle$ since $P(P|\psi\rangle) = |\psi\rangle$, in which the wave function ψ has even parity for eigenvalue +1 and odd parity for eigenvalue -1, and the parity of wave function is conserved and it is one of intrinsic properties of wave function because it cannot be distinguished in physical phenomena as $(\langle\psi|P^*)(P|\psi\rangle) = \langle\psi|\psi\rangle$, in which $P^* \cdot P = 1$.

Now, let's review a parity transformation as $(x, y, z) \Rightarrow (x', y', z') = (x, y, -z)$, which is similar to the reflected image in a mirror (reflection) reversing left and right and changing right-hand rule to left-hand rule in physics. If we remember that the right-hand rule in physics is just a conventional choice, physics laws should be invariant in the mirror image system with left-hand rule. Fig. (1) shows two Cartesian coordinate systems: right-handed system (a) and left-handed system (b), in which the left-handed system is the mirror image of the right-handed system and vice versa. Between two mirror-image systems an axial vector (or pseudovector) that can be expressed as $\vec{A} = \vec{b} \times \vec{c}$ in right-handed system changes as $\vec{A}' = -\vec{A}$ in left-handed system.

For example, let's say, a charge q is moving with velocity $\vec{v}$ under the influence of magnetic field $\vec{B}$ applied in an experiment; then, the force acting on the charge $\vec{F} = q\left(\vec{v} \times \vec{B}\right)$ in right-handed system; however, in left-handed system it can be expressed as $\vec{F} = q\left(\vec{v} \times \vec{B}'\right)$, in which $\vec{B}' = -\vec{B}$.

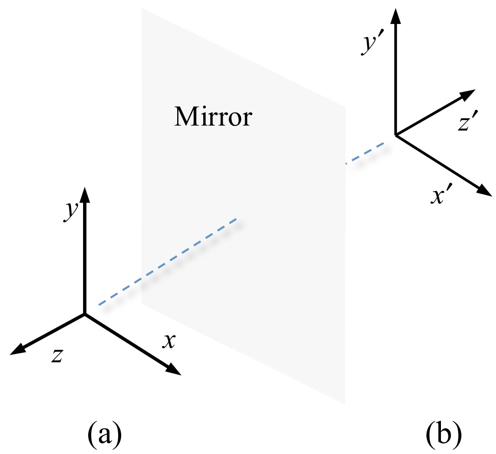

Fig. 1: parity transformation $\left(x', y', z'\right) = \left(x, y, -z\right)$

In fact, magnetic field $\vec{B}$ is pseudovector as torque, angular momentum, etc. Hence, if the direction of magnetic field $\vec{B}$ is reversed in the experiment, it can simulate the left-handed system or generate phenomena in left-handed system, which means that the handedness (helicity) of a particle in right-handed system is changed; the handedness of right-handed particle changes to left-handed particle, and vice versa in left-handed system.

Nevertheless, it has been known that only left-handed neutrinos have been observed (Wu and al. 1957), which is parity violation in weak interaction saying that only left-handed neutrinos exist in nature. However, before we accept blindly the parity violation as an undeniable fact in natural phenomena, we need to investigate how it can be possible in experiments with the magnetic fields.

In natural phenomena one of the basic principles is equality, which means: it should be expected that any physical event in nature is equally possible as long as there is no pre-condition against it. In addition, the conservation of parity is not based on phenomenology but the reasonable inference as shown above, which should be true in general. Then, we should wonder why right-handed system or left-handed system is not the conventional choice especially in weak interaction. In an experiment of parity test, which is similar to the mirror image of a physical object, people use magnetic fields for the mirror effect; then, it can be asked whether the use of magnetic fields affects on the experimental result besides producing the mirror effect.

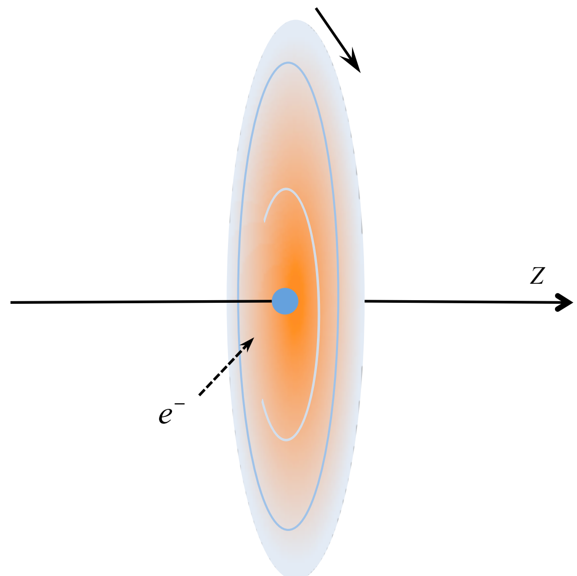

Fig. 2: schematic representation of W^- boson

In the classical models of proton and neutron (Kim 2022), those of which are composite spinning objects with electric charge distribution, neutron has positive charge at the center (e^+), while the same amount of negative charge is distributed on its surface. The free neutron that is not bounded inside the nucleus is not stable[2] but decays as $n^0 \to p^+ + W^-$ and then $W^- \to e^- + \bar{\nu}_e$, which is called beta decay. Fig. (2) shows the schematic drawing for the internal structure of W^- boson, in which the electron is at the center with spin $\frac{1}{2}\hbar$ and surrounding vacuum particles (positrons) also have dynamic rotations, which should be corresponded to the angular momentum of $\frac{1}{2}\hbar$ because W^- boson has spin $1\,\hbar$.

We can find a possible explanation for the process of beta decay with the classical models of nucleons and the model of W^- boson in physical vacuum space as shown in Fig. (2): in the beta decay of a neutron, the negative charge distribution on the surface is stripped off and the remaining part with positive charge at the center becomes a proton. However, the stripped part with negative charge distribution still has an angular momentum, in which vacuum particles,

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[2] lifetime of a neutron: $\tau_n \sim 15$ min

those of which have positive charges with the angular momentum, generate a magnetic field; then, due to the magnetic field vacuum particles are pushed outward, while the negative charge distribution is converged to the center of the distribution, which is the electron in Fig. (2).

The surrounding vacuum particles and the electron at the center in Fig. (2) are not stable because there is a magnetic interaction between the magnetic fields generated by the rotating vacuum particles (positrons) and the spin magnetic moment of electron. In $\sim 10^{-25}$ seconds that is the lifetime of W^- boson, it decays to an electron and a neutrino.

If a magnetic field is applied in the z direction in Fig. (2), the spin of electron and the angular momentum of vacuum particles both are aligned to the z direction, the rotating vacuum particles are attracted to negative z direction, which makes a bundle of longitudinal vacuum-string waves with left-handed rotation (negative helicity). Now, if the direction of magnetic field is reversed, which is in negative z direction, with expecting physical phenomena in left-handed system like a mirror images, the spin of electron and the angular momentum of vacuum particles both are aligned to the negative z direction, and the rotating vacuum particles are attracted to positive z direction with left-handed rotation as before.

It seems that the conservation of parity is not valid in weak interaction since only left-handed neutrinos are detected in both experiments of right-handed system and the left-handed system that is supposed to be simulated with reversing the direction of magnetic field. However, the reversed magnetic field doesn't generate physical phenomena like mirror images in left-handed system because magnetic field itself affects on the result in experiments as shown above. Therefore, we cannot say that there is parity violation in weak interaction. As suggested with the model of W^- boson as above, the left-handed and right-handed neutrinos should be equally possible, and like photon neutrino has not antiparticle since neutrino is supposed to be a bundle of longitudinal vacuum-string waves in physical vacuum space.

Neutrino Flavor Oscillation

In the theory of neutrino oscillation, the flavor of a neutrino such as electron, muon, or tau neutrino is corresponded to a specific phase in the superposition of three mass eigenstates, in which each mass eigenstate is represented by a wave function in quantum mechanics (almost a plane wave with extremely high momentum with non-zero small mass) with the phase determined by the mass and energy. Then, three different wave functions are superposed; the superposed state of three mass eigenstates, which represents neutrino in general, keeps being changed in propagation.

The three mass eigenstates and three flavor eigenstates can be transferred to each other through a transformation matrix with so-called mixing parameters, which is the unitary transformation in quantum mechanical description for neutrino oscillation. In the theory, the flavor eigenstates are corresponded to ν_e, ν_μ, and ν_τ, those of which can be confirmed in phenomena with the corresponding charged leptons in charged-current (CC) neutrino interactions; however, the mass eigenstates are not connected to phenomena directly even though the eigenstates are evolving in time and space. Correspondingly, the mixed mass eigenstate of all three mass eigenstates should be evolving continuously in time and space. Then, it is questionable how only one of three neutrino flavors is represented in phenomena at any time and any point in space during the propagation of neutrino. The question is not for the mathematical description but for the physical reality in the theory of neutrino oscillation. In other words, the question is whether the distinctive three flavors of neutrinos are complete in the theory or simply enough to explain for the oscillation of neutrino flavors. Even in the mathematical description, the transformation should be mutual for both sides, flavor eigenstates and mass eigenstates, being described with same space and time; nevertheless, one side, the description with neutrino flavors, is in physical phenomena but the other side, the description with mass eigenstates, is not realized in physics even though each mass eigenstate can be expressed with a linear combination of neutrino flavor eigenstates.

In the theory of neutrino oscillation, physical mass is needed to explain the change of neutrino flavors; however, the mass itself might be a self-contradictory factor in the theory because the physical masses in the mass eigenstates cannot be identified or localized. If the mass eigenstates or the superposed state is discussed inside a nucleus, it makes sense in approximation; however, the physical system in neutrino oscillation can be the whole universe. Then, we have to ask the physical reality about the physical masses in mass eigenstates or literally physical distances between the physical masses after traveling a long distance in space. If the physical distances are not maintained as the same as before, the change of neutrino flavors is still possible in neutrino oscillation?

It seems that the mass eigenstate in the theory is making an additional quantum layer, which is not linked to physical phenomena directly, but in which all the information is transferred to the flavor eigenstates through the transformation matrix, which then can be realized in physics. In the theory of neutrino oscillation, it should be explained why the additional quantum description is necessary especially for the neutrino oscillation, why it is not observable in physical phenomena, and what it is in the view of physical reality. However, in quantum mechanics we don't ask this kind of question in usual because the eigenstate itself doesn't represent physical reality until a measurement is made.

The theory of neutrino oscillation is unconventional theory because the fundamental question of quantum reality, which is used to be concerned about the possible quantum states of one physical entity, is deformed and more argumentative in the theory of neutrino oscillation. If the theory of neutrino oscillation is true, in which each mass eigenstate alone doesn't represent reality in physics, it is not compatible with the many-worlds interpretation in quantum reality; however, the "Einstein's Moon", which is about objectively existing of physical matter no matter whether it is observed to not, can be still in the list of discussion. Nevertheless, the interpretation of Einstein's Moon in quantum physics is so drastic and still awkward, too.

In 4-D complex space, the ontological reality of neutrino is a bundle of longitudinal vacuum-string waves in physical vacuum space. In Fig. (3) two possible modes of longitudinal vacuum-string waves is shown, in which the density of vacuum-string numbers should be proportional to the energy of neutrino with the longitudinal vacuum-string wave motions and also proportional to the interaction probability of neutrino with matters. It is supposed that the flavors of neutrinos such as ν_τ , ν_μ , and ν_e are related to the number density of longitudinal vacuum-string waves: each flavor of neutrino should be corresponded from high number density to low number density of longitudinal vacuum-string waves respectively if we consider masses of charged leptons as $m_\tau > m_\mu > m_e$ (Particle Data Group) and the model of W^- boson shown in Fig. (2).

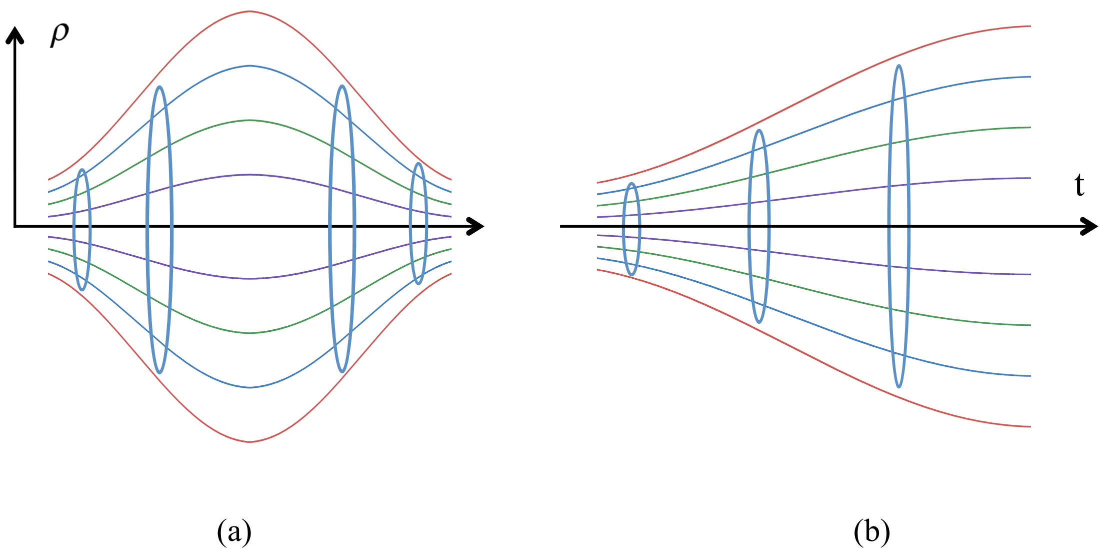

Fig. 3: Two possible modes of neutrino flavor changes

When a bundle of longitudinal vacuum-string waves are released from W^- boson shown in Fig. (2), the released vacuum-string waves can be diffused as shown in Fig. (3b). In another words, the flavor of neutrino can be changed to another flavors with low number density of vacuum-string waves, which is not the oscillation of neutrino flavors. However, the flavor of neutrino cannot be changed from a flavor with low number density to a flavor with high number density of longitudinal vacuum-string waves, which means that ν_μ can be changed to ν_e but not to ν_τ. In addition, the diffusion process can be reached to a dissociated state of the bundle of longitudinal vacuum-string waves as $\nu_\tau \to \nu_\mu \to \nu_e \to \nu$, $\nu_\mu \to \nu_e \to \nu$, and $\nu_e \to \nu$; then, the longitudinal vacuum-string waves are just a bunch of longitudinal plane waves without any interaction with others and not even observable entities in physical phenomena.

However, if the diffusion is only way for the change of neutrino flavors, we cannot explain the astrophysical neutrinos detected on the Earth, those of which are supposed to be coming from astrophysical objects in far away distances, for example, Supernova 1987A is 1.68×10^5 light-years away. Therefore, we need to consider another possible case as shown in Fig. (3a), in which neutrino has a transverse mode of oscillation in radial direction and the flavors of neutrinos can be oscillated.

Let's say, for the rotating vacuum particles in the positive z-direction as shown in Fig. (2), in which net angular momentum is supposed to be $\frac{1}{2}\hbar$, a bunch of pulses is triggered toward negative z-direction by the magnetic interaction between those rotating vacuum particles and a magnetic field B applied in the positive z-direction. Then, momentums of the pulses are transferred to vacuum particles, and a bundle of longitudinal vacuum-string waves is generated in the negative z-direction.

In Fig. (4), the bundle of longitudinal vacuum-string waves is going into the page, which represents a left-handed neutrino (ν_L); each vacuum-string wave has a tangential momentum p for the handedness of neutrino and a driving force F_{diff} is expected as $F_{diff} \propto -\nabla_\rho n_{string}(\rho)$ for the diffusion in radial direction, in which $n_{string}(\rho)$ is vacuum-string number density in the longitudinal vacuum-string waves.

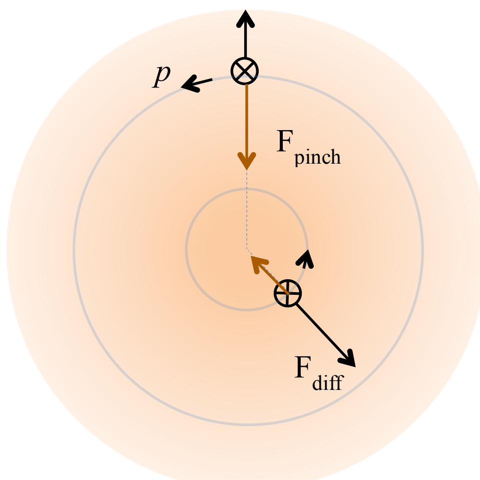

Fig. 4: the radial cross section of longitudinal vacuum-string waves

If there is nothing to hold the bundle of longitudinal vacuum-string waves against the diffusion, it should be just a diffusion in radial direction because the electron in W^- boson shown in Fig. (2), in which the electron is holding vacuum particles nearby, is absent in the distribution of longitudinal vacuum-string waves in Fig. (4). On the other hand, if the bundle of longitudinal vacuum-string waves also has a transverse oscillation in radial direction as shown in Fig. (3a), there should be a mechanical force F_{pinch} against the force F_{diff} as shown in Fig. (4).

Now, let's consider that the longitudinal motion of vacuum-strings in a bundle can have positive current effects, which produce magnetic fields in tangential direction; then, we can expect a magnetic force as the pinch effect in plasma physics. The mechanical force F_{pinch} should be the magnetic force on the longitudinal vacuum-string waves under the influence of magnetic fields $B(\rho)$ that is produced by the current $I(\rho)$ passing through the cross-section area of radius ρ, in which $I(\rho) \sim \upsilon_v \int_0^\rho n_{string}(\rho)\, \rho d\rho$ and υ_v is the speed of longitudinal vacuum-string waves in a bundle, and that has ρ^{-1} dependency due to the axial symmetry. The force F_{pinch} can be expressed as $F_{pinch} \propto \upsilon_v\, B(\rho)$ for the vacuum-strings at radius ρ in the longitudinal vacuum-string waves, that is

$$F_{pinch}(\rho) \propto -\frac{E_v}{\rho} \int_0^\rho n_{string}(r)\, rdr \qquad (1)$$

with supposing that $E_v \propto (\upsilon_v)^2$.

Neutrino, which is a bunch of pulses in a bundle of longitudinal vacuum-string waves, is expected to start the diffusion in radial direction; the driving force for diffusion, $F_{diff} \propto -\nabla_\rho n_{string}(\rho)$, is getting weaker in radial distance ρ; then, if the force $|F_{pinch}|$ is bigger than $|F_{diff}|$ at the distance ρ, the bundle of longitudinal vacuum-string waves is contracted and being tightened. If there is an equilibrium point in the effective potential function $\phi(\rho)$ that can be defined as $-\nabla_\rho \phi(\rho) = F_{diff} + F_{pinch}$, the distribution of vacuum-string number density $n_{string}(\rho)$ is oscillating through the equilibrium point, in which E_v in Eqn. (1) is the critical factor to determine whether the transverse oscillation is possible; if then, how frequently it is repeated (frequency), and how many flavors of neutrinos are involved (amplitude). On the other hand, if E_v is so low, the transverse oscillation is not even possible and only the diffusion takes place.

Considering that $F_{pinch} \propto E_v$ in Eqn. (1), the frequency and the amplitude in neutrino oscillation should be determined by neutrino energy E_v. Although the energy dependency is also shown with parameter L/E_v in experiments and the theory of neutrino oscillation, it is not clear yet how many neutrino flavors are involved in the oscillation.

However, we can show the E_v dependency with a simple example as following, which is not realistic though: Since the radius of bundle of longitudinal vacuum-string waves is supposed to be extremely small, the effective potential function $\phi(\rho)$ can be expressed as

$\phi(\rho) = a_0 + a_1\rho + a_2\rho^2 + \cdots \quad (\rho << 1)$. Let's say, if $n_{string}(\rho) \approx -A\rho + B$ with positive constants A and B, in which $\rho \le \frac{B}{A}$ and $B = \left(6NA^2\right)^{\frac{1}{3}}$ since $n_{string}(\rho) \ge 0$ and total number of vacuum-string waves N should be constant. Then, $F_{diff}(\rho) \sim \frac{A}{\varepsilon_v}$ and $F_{pinch}(\rho) \sim -\mu_v \frac{\upsilon_v^2}{\rho}\left(-\frac{1}{3}A\rho^3 + \frac{1}{2}B\rho^2\right)$ with constants ε_v and μ_v for the longitudinal vacuum-string waves in physical vacuum space. Since we cannot estimate the value of ε_v or μ_v at this time, instead of ε_v and μ_v, let's use ε_0 and μ_0, just for convenience, to see the behaviors of effective potential function $\phi(\rho)$.

Then, the effective potential function can be expressed as $\phi(r) \propto \beta^2\left(-\frac{1}{9}r^3 + \frac{1}{4}r^2\right) - \frac{1}{\rho_0^2}r$ where

$\beta = \frac{\upsilon_v}{c}$, $c = (\varepsilon_0\mu_0)^{-\frac{1}{2}}$, $\rho_0 \equiv \frac{B}{A} = \left(\frac{6N}{A}\right)^{\frac{1}{3}}$, $r = \frac{\rho}{\rho_0}$, and $r \le 1$.

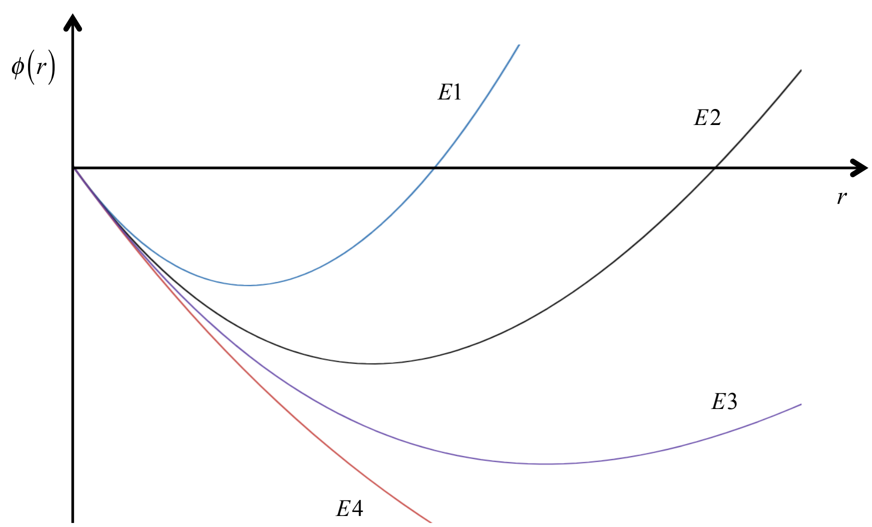

Fig. 5: E_v dependency: $E1 > E2 > E3 > E4$

Although it is not to scale but rather close to a schematic drawing, the effective potential function $\phi(r)$ is shown in Fig. (5) representing the dependency of neutrino energy E_v for the oscillation amplitude; if the number density of vacuum-string waves is oscillating through the minimum point of effective potential function $\phi(r)$, which is supposed to be the neutrino oscillation in 4-D complex space, we can see in Fig. (5); the higher neutrino energy is, the smaller Δr is expected from the minimum point in the oscillation.

Since the number density of longitudinal vacuum-string waves is supposed to be proportional to the corresponding charged lepton mass as $n_{\nu_\tau} > n_{\nu_\mu} > n_{\nu_e}$ in which $m_\tau > m_\mu > m_e$, it is expected that the number density of vacuum-string waves in the neutrino involved in neutrino oscillation should be lower than the number density of initial neutrino.

For example, electron neutrino ν_e will disappear and reappear as $\nu_e \to \nu_? \to \nu_e$, in which $\nu_?$ has a lower number density of vacuum-string waves than ν_e, On the other hand, muon neutrino ν_μ can oscillate depending on the neutrino energy as shown in Fig. (5), which can be as $\nu_\mu \to \nu_e \to \nu_? \to \nu_e \to \nu_\mu$ for low ν_μ energy; $\nu_\mu \to \nu_e \to \nu_\mu$, or $\nu_\mu \to \nu_? \to \nu_\mu$ for high ν_μ energy, in which $\nu_?$ has a lower number density than ν_μ but higher number density than ν_e. Similarly, if tau neutrino ν_τ participates in the oscillation; $\nu_\tau \to \nu_\mu \to \nu_e \to \nu_? \to \nu_e \to \nu_\mu \to \nu_\tau$, $\nu_\tau \to \nu_\mu \to \nu_e \to \nu_\mu \to \nu_\tau$, $\nu_\tau \to \nu_\mu \to \nu_\tau$, or $\nu_\tau \to \nu_? \to \nu_\tau$ depending on the neutrino energy.

By the way, for the neutrino $\nu_?$, the flavor of which cannot be identified as ν_e, ν_μ, or ν_τ, the charged-current (CC) neutrino interaction, which is mediated by $\mathrm{W}^\pm$ bosons, cannot be expected; however, neutral-current (NC) neutrino interaction mediated by Z^0 boson is still expected.

Mass and Speed of Neutrino

In the theory of neutrino oscillation, neutrinos have non-zero masses; in fact, for the question whether neutrino has a mass or not, physicists already had reasonable suspicions in tritium beta decay spectrum before the theory of neutrino oscillation arouse (The KATRIN Collaboration 2022). "In 1934, Enrico Fermi pointed out that, if the neutrino had mass, it would subtly distort the tail of this spectrum" (Bowles and Robertson 1997).

In tritium beta decay as ${}^3_1\mathrm{H} \to {}^3_2\mathrm{He} + e^- + \bar{\nu}_e$, the helium-3 nucleus is much heavier than the electron and the neutrino (if $m_\nu \neq 0$); hence, the electron and the neutrino share almost all of the energy released from the beta decay. If the neutrino has no mass, the beta decay spectrum is supposed to be smooth including the limit in which the electron takes all of the energy; however, the spectrum is not smooth near the limit, which makes people think that neutrino might have a mass.

Now, we can explain why the limitation of electron energy appears somewhat subtle but obviously in the beta decay spectrum and what it is. If neutrino has not only the longitudinal wave motion but also has the transverse oscillation or takes the diffusion process as shown in Fig.

(3), it can suggest that the energy of neutrino has two contributions, mainly from the longitudinal vacuum-string waves and minimally from the radial motions such as transverse oscillation or diffusion in radial direction.

Let's think about the conservation of energy and momentum for the electron and the neutrino in the rest frame of W^- boson. In Fig. (3), the radial motions, such as transverse oscillation or diffusion in radial direction, have zero net momentum due to the axial symmetry. In axial direction, the momentum and energy of electron is determined with the longitudinal vacuum-string waves. In other words, the radial motions in the longitudinal vacuum-string waves are independent of momentum conservation of the electron and the neutrino generated from W^- boson shown in Fig. (2). Then, the energy for the radial motions in the bundle of longitudinal vacuum-string waves should be subtracted from the maximum energy that electron can take, which appears in the end-point of beta decay spectrum and has been interpreted as neutrino mass.

Although neutrino is not a massive particle but described as a bundle of longitudinal vacuum-string waves in physical vacuum space, it might also have the transverse oscillation or the diffusion process in radial direction as shown in Fig. (3), which means that neutrino has a mass-effect in phenomena, for example, in tritium beta decay spectrum. If the bundle of vacuum-string waves is dissociated, which can be the end status of diffusion process shown in Fig. (3b), the energy of the longitudinal plane waves can be considered as background energy in physical vacuum space, and the speed of plane waves in longitudinal mode can be supposed as $c_v = c$ in an ideal case for physical vacuum space; however, it also can be different due to the geometry of physical vacuum space.

In addition, the speed of longitudinal vacuum-string waves, no matter which is in a bundle or not, should be constant for all observers regardless of their relative motions like the speed of light in free space (Kim 1997). Meanwhile, as long as the bundle of vacuum-string waves is maintained in a bundle, the speed of neutrino υ_v should be less than the speed of longitudinal plane waves as $\upsilon_v < c_v$ in free space in comparison of the group velocity in quantum mechanics that is always less than the speed of light, which is the speed of transverse plane waves in physical vacuum space.

Discussion

Neutrino is a bundle of longitudinal vacuum-string waves in 4-D complex space; however, it also has radial motions, transverse oscillation or diffusion process, in which the flavor of neutrino can be changed with the radial motions and the energy for the radial motions can be identified with mass effects in phenomena such as in tritium beta decay spectrum.

With the model of W^- boson, once again we showed that the parity violation in weak interaction should not be true. The conservation of parity is supposed to be still valid in weak interaction in that the logical reasoning for the conservation of parity can be more fundamental than seemingly clear physical evidences in experiments. Therefore, neutrino has no rest mass and no antiparticle like photon, and right-handed and left-handed neutrinos both are equally possible in phenomena.

In fact, neutrino is not in the scope of special relativity because neutrino is a bundle of longitudinal vacuum-string waves, while light is transverse mode in vacuum-string waves in physical vacuum space. The speed of neutrino υ_ν should be less than the speed of longitudinal plain waves in free space as $\upsilon_\nu < c_\nu$, in which c_ν can be different from the speed of light in free space; however, it can be supposed as $c_\nu = c$ in an ideal case for physical vacuum space.

The neutrino oscillation is also possible in 4-D complex space; however, it is not in the same way as in the theory of neutrino oscillation that people have known: all the flavors of neutrinos such as ν_e, ν_μ, and ν_τ are not involved in general; however, if a flavor of neutrino participates in the oscillation, its charged lepton has lower mass than the charged lepton of the neutrino at the beginning. In addition, the number of neutrino flavors involved in the oscillation is dependent on neutrino energy: for example, $\nu_\mu \to \nu_e \to \nu_? \to \nu_e \to \nu_\mu$ for low energy ν_μ, while for high energy ν_μ, $\nu_\mu \to \nu_{??} \to \nu_\mu$, in which neutrino $\nu_?$ or $\nu_{??}$ is not a kind of neutrinos such as ν_τ, ν_μ, and ν_e, each of which has a corresponding charged lepton in CC neutrino interaction; thus, for neutrino $\nu_?$ or $\nu_{??}$, the charged-current (CC) neutrino interaction is not expected; however, the neutral-current (NC) neutrino interaction should be possible.

Since astrophysical neutrinos are supposed to travel such long cosmic distances from astrophysical objects to the Earth, the flavors of neutrinos should be averaged out through neutrino oscillations, and all the flavors of neutrinos involved in the oscillations should be equally possible at the Earth. For example, if the flavor ratio of neutrinos is given as $\left(\nu_e : \nu_\mu : \nu_\tau\right) = \left(E : M : 0\right)$ at the source of neutrinos and expected as $\left(E : M : 0\right) \to \left(e : m : t\right)$ at detectors on the Earth, $\frac{e}{m} > \frac{E}{M}$ in general, especially for low energy neutrinos, while $\frac{e}{m} \approx \frac{E}{M}$ for high energy neutrinos; however, tau neutrino is not expected at all $\left(t = 0\right)$.

If we investigate carefully the flavor composition of astrophysical neutrinos, it might give us crucial information to understand the reality of neutrino oscillation.

Works Cited

Bowles, Thomas J., and R. G. Hamish Robertson. "Tritium Beta Decay and the Search for Neutrino Mass." *Los Alamos Science*, no. 25 (1997).

Cowan, C. L., and et al. "Dtection of the Free Neutrino: a Comfirmation." *SCIENCE* 124, no. 3212 (July 1956).

Crease, Robert P. *The bizarre logic of the many-worlds theory.* September 02, 2019. https://www.nature.com/articles/d41586-019-02602-8.

Dimitropoulos, Stav. "Objective Reality May Not Exist at All, Quantum Physiciists Say." *Popular Mechanics.* Jun 29, 2022. https://www.popularmechanics.com/science/a40460495/objective-reality-may-not-exist/.

Gribbin, John. "The Many-Worlds Theory, Explained." *THE MIT PRESS READER.* May 20, 2020. https://thereader.mitpress.mit.edu/the-many-worlds-theory/.

Kajita, Takaaki. "Atmospheric Neutrinos and Discovery of Neutrino Oscillations." *Proceedings of the Japan Academy, Series B.* Physical and Biological Sciences, 2010. 303-321.

Katori, Teepee. *Neutrino Observatories.* November 22, 2022. https://conference.ippp.dur.ac.uk/event/1144/contributions/5919/attachments/4718/5877/TK_HEPForum22.pdf.

Kim, Kiyoung. "Neutrino and Parity Violation in Weak Interaction." *arXiv.org e-Print archive.* November 30, 1998. https://arxiv.org/pdf/hep-ph/9811522v1.pdf.

—. "Paradigm Shift in Physics." *viXra.org e-Print archive.* February 15, 2017. http://vixra.org/pdf/1702.0179v1.pdf.

—. "Physical Foundation of Pauli Exclusion Principle and Nuclear Force." *viXra.org e-Print archive.* September 13, 2022. https://vixra.org/pdf/2209.0079v2.pdf.

—. "The Wave Function in Quantum Mechanics." *arXiv.org e-Print archive.* January 1997. https://arxiv.org/pdf/quant-ph/9701023v3.pdf.

Learned, John. "DISCOVERY OF NEUTRINO MASS AND OSCILLATIONS." *phys.hawaii.edu.* October 2015. https://www.phys.hawaii.edu/~jgl/nuosc_story.html.

Neutrino Research. *Neutrino Resources.* https://voices.uchicago.edu/neutrino/resources/.

Neutrino Science. *Neutrino Science.* June 2023. https://neutrino-science.com/.

Particle Data Group. "The Review of Particle Physics (2022)." *PDG.* https://pdg.lbl.gov.

Siegfried, Tom. *Quantum reality.* 2023. https://www.sciencenews.org/century/quantum-physics-theory-revolution-reality-uncertainty.

SLAC. "Neutrino Group, Neutrino Oscillation." *SLAC National Accelerator Laboratory.* https://sites.slac.stanford.edu/neutrino/research/neutrino-oscillations.

SNO Collaboration. "The Sudbury Neutrino Observatory." *arXiv.org e-Print archive.* February 8, 2016. https://arxiv.org/pdf/1602.02469.pdf.

The KATRIN Collaboration. "Direct neutrino-mass measurement with sub-electronvolt sensitivity." *Nature Physics* 18 (February 2022): 160-166.

Wiki_Quantum_Reality. "Interpretation of quantum mechanics." *Wikipedia.* May 7, 2023. https://en.wikipedia.org/wiki/Quantum_Reality.

Wu, C. S., and et al. "Experimental Test of Parity Conservation in Beta Decay." *Physical Review* (American Physical Society) 105, no. 4 (February 1957): 1413.