Quark Annihilation and Lepton Formation versus Pair Production and Neutrino Oscillation: The Fourth Generation of Leptons

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The emergence or formation of leptons from particles composed of quarks is still remained very poorly understood. In this paper, we propose that leptons are formed by quark-antiquark annihilations. There are two types of quark-antiquark annihilations. Type-I quark-antiquark annihilation annihilates only color charges, which is an incomplete annihilation and forms structureless and colorless but electrically charged leptons such as electron, muon, and tau particles. Type-II quark-antiquark annihilation annihilates both electric and color charges, which is a complete annihilation and forms structureless, colorless, and electrically neutral leptons such as electron, muon, and tau neutrinos. Analyzing these two types of annihilations between up and down quarks and antiquarks with an excited quantum state for each of them, we predict the fourth generation of leptons named lambda particle and neutrino. On the contrary quark-antiquark annihilation, a lepton particle or neutrino, when it collides, can be disintegrated into a quark-antiquark pair. The disintegrated quark-antiquark pair, if it is excited and/or changed in flavor during the collision, will annihilate into another type of lepton particle or neutrino. This quark-antiquark annihilation and pair production scenario provides unique understanding for the formation of leptons, predicts the fourth generation of leptons, and explains the oscillation of neutrinos without hurting the standard model of particle physics. With this scenario, we can understand the recent OPERA measurement of a tau particle in a muon neutrino beam as well as the early measurements of muon particles in electron neutrino beams.

1 Introduction

Elementary particles can be categorized into hadrons and leptons in accord with whether they participate in the strong interaction or not. Hadrons participate in the strong interaction, while leptons do not. All hadrons are composites of quarks [1-3]. There are six types of quarks denoted as six different flavors: up, down, charm, strange, top, and bottom, which are usually grouped into three generations: $\{u, d\}$, $\{c, s\}$, $\{t, b\}$. Color charge is a fundamental property of quarks, which has analogies with the notion of electric charge of particles. There are three varieties of color charges: red, green, and blue. An antiquark's color is antired, antigreen, or antiblue. Quarks and antiquarks also hold electric charges but they are fractional, $\pm e/3$ or $\pm 2e/3$, where $e = 1.6 \times 10^{-19}$ C is the charge of proton.

There are also six types of leptons discovered so far, which are electron, muon, and tau particles and their corresponding neutrinos. These six types of leptons are also grouped into three generations: $\{e^-, \nu_e\}$, $\{\mu^-, \nu_\mu\}$, $\{\tau^-, \nu_\tau\}$. The antiparticles of the charged leptons have positive charges. It is inappropriate to correspond the three generations of leptons to the three generations of quarks because all these three generations of leptons are formed or produced directly in association with only the first generation of quarks. We are still unsure that how leptons form and whether the fourth generation of leptons exists or not [4-8].

In this paper, we propose that leptons, including the fourth generation, are formed by quark-antiquark annihilations. Electrically charged leptons are formed when the color charges of quarks and antiquarks with different flavors are annihilated, while neutrinos are formed when both the electric and color charges of quarks and antiquarks with the same flavor are annihilated. We also suggest that quarks and antiquarks can be produced in pairs from disintegrations of leptons. This quark-antiquark annihilation and pair production model predicts the fourth generation of leptons and explains the measurements of neutrino oscillations.

2 Quark Annihilation and Lepton Formation

Quark-antiquark annihilation is widely interested in particle physics [9-13]. A quark and an antiquark may annihilate to form a lepton. There are two possible types of quark-antiquark annihilations. Type-I quark-antiquark annihilation only annihilates their color charges. It is an incomplete annihilation usually occurred between different flavor quark and antiquark and forms structureless and colorless but electrically charged leptons such as e^-, e^+ , μ^-, μ^+, τ^-, and τ^+. Type-II quark-antiquark annihilation annihilates both electric and color charges. It is a complete annihilation usually occurred between same flavor quark and antiquark and forms

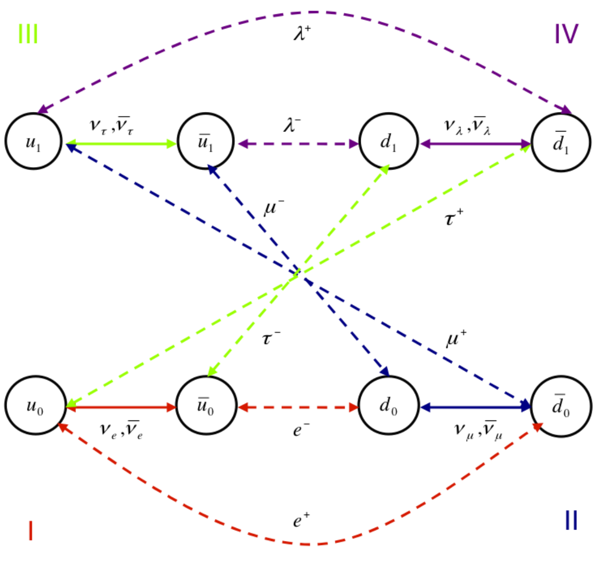

Fig. 1: Formation of the four generations of leptons by annihilations of up and down quarks and antiquarks with an excited quantum state.

structureless, colorless, and electrically neutral leptons such as ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$, ν_τ, and $\bar{\nu}_\tau$.

Mesons are quark-antiquark mixtures without annihilating their charges. For instance, the meson pion π^+ is a mixture of one up quark and one down antiquark. Meson's color charges are not annihilated and thus participate in the strong interaction. Leptons do not participate in the strong interaction because their color charges are annihilated. Particles formed from annihilations do not have structure such as γ-rays formed from particle-antiparticle annihilation. A baryon is a mixture of three quarks such as that a proton is composed of two up quarks and one down quark and that a neutron is composed of one up quark and two down quarks.

Recently, Zhang [14-15] considered the electric and color charges of quarks and antiquarks as two forms of imaginary energy in analogy with mass as a form of real energy and developed a classical unification theory that unifies all natural fundamental interactions with four natural fundamental elements, which are radiation, mass, electric charge, and color charge. According to this consideration, the type-I quark-antiquark annihilation cancels only the color imaginary energies of a quark and a different flavor antiquark, while the type-II quark-antiquark annihilation cancels both the electric and color imaginary energies of a quark and a same flavor antiquark.

Figure 1 is a schematic diagram that shows formations of four generations of leptons from annihilations of up and down quarks and antiquarks with one excited quantum state for each of them. The existence of quark excited states, though not yet directly discovered, has been investigated over three decades [16-18]. That ρ^+ is also a mixture of one up

Quarks	u_0	d_0	u_1	d_1
$\bar{u}_0$	ν_e, $\bar{\nu}_e$	e$^-$	-	τ^-
$\bar{d}_0$	e$^+$	ν_μ, $\bar{\nu}_\mu$	μ^+	-
$\bar{u}_1$	-	μ^-	ν_τ, $\bar{\nu}_\tau$	λ^-
$\bar{d}_1$	τ^+	-	λ^+	ν_λ, $\bar{\nu}_\lambda$

Table 1: The up and down quarks and antiquarks in ground and excited quantum states and four generations of leptons

quark and one down antiquark but has more mass than π^+ and many similar examples strongly support that quarks and antiquarks have excited states. In Figure 1, the subscript '0' denotes the ground state and '1' denotes the excited state. The higher excited states are not considered in this study. The dashed arrow lines refer to type-I annihilations of quarks and antiquarks that form electrically charged leptons, while the solid arrow lines refer to type-II annihilations of quarks and antiquarks that form colorless and electrically neutral leptons. These annihilations of quarks and antiquarks and formations of leptons can also be represented in Table 1.

The first generation of leptons is formed by annihilations between the ground state up, ground state antiup, ground state down, and ground state antidown quarks (see the red arrow lines of Figure 1). The up quark u_0 and the antiup quark $\bar{u}_0$ completely annihilate into an electron neutrino ν_e or an electron antineutrino $\bar{\nu}_e$. The antiup quark $\bar{u}_0$ and the down quark d_0 incompletely annihilate into an electron e^-. The up quark u_0 and the antidown quark $\bar{d}_0$ incompletely annihilate into a positron e^+.

The second generation of leptons are formed by annihilations between the ground state down, ground state antidown, excited up, and excited antiup quarks (see the blue arrow lines of Figure 1). The down quark d_0 and the antidown quark $\bar{d}_0$ completely annihilate into a muon neutrino ν_μ or an antimuon neutrino $\bar{\nu}_\mu$. The antiup quark $\bar{u}_1$ and the down quark d_0 incompletely annihilate into a negative muon μ^-. The up quark u_1 and the antidown quark $\bar{d}_0$ incompletely annihilate into a positive muon μ^+.

The third generation of leptons are formed by annihilations between the ground state up, excited up, ground state antiup, excited antiup, excited down, and excited antidown quarks (see the green lines of Figure 1). The up quark u_1 and the antiup quark $\bar{u}_1$ completely annihilate into a tau neutrino ν_τ or a tau antineutrino $\bar{\nu}_\tau$. The antiup quark $\bar{u}_0$ and the down quark d_1 incompletely annihilate into a negative tau τ^-. The up quark u_0 and the antidown quark $\bar{d}_1$ incompletely annihilate into a positive tau τ^+.

The fourth generation of leptons are formed by annihilations between excited up, excited antiup, excited down, and excited antidown quarks (see the purple lines of Figure 1). The down quark d_1 and the antidown quark $\bar{d}_1$ completely annihilate into a lambda neutrino ν_λ or a lambda antineutrino

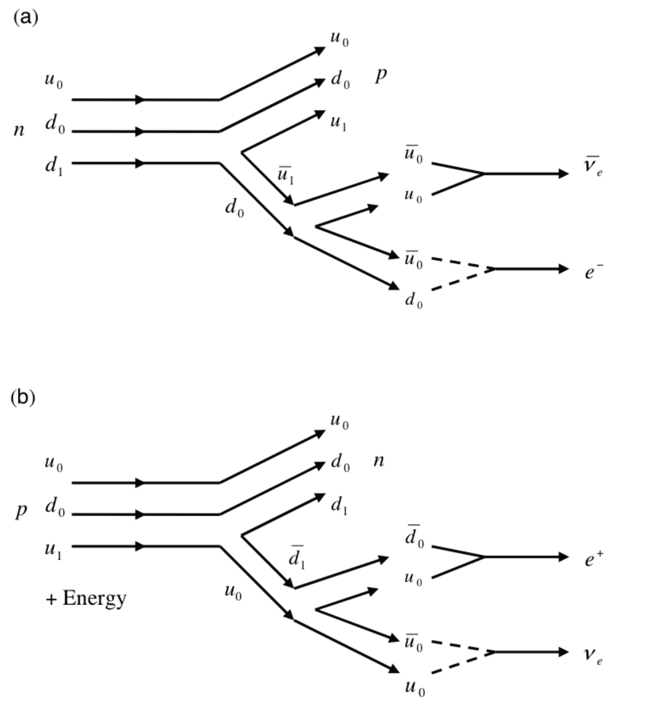

Fig. 2: Formation of the first generation of leptons: (a) e$^-$ and $\bar{\nu}_e$ through beta decay and (b) e$^+$ and ν_e through positron emission.

$\bar{\nu}_\lambda$. The antiup quark $\bar{u}_1$ and the down quark d_1 incompletely annihilate into a negative lambda λ^-. The up quark u_1 and the antidown quark $\bar{d}_1$ incompletely annihilate into a positive lambda λ^+.

3 Quark Pair Production and Lepton Disintegration

The first generation of leptons can be produced through the beta decay of a neutron, $n \longrightarrow p + e^- + \bar{\nu}_e$ (Figure 2a), and the positron emission of a proton, energy + $p \longrightarrow n + e^+ + \nu_e$ (Figure 2b).

In the beta decay, an excited down quark in the neutron degenerates into a ground state down quark and an excited up and antiup quark pair, $d_1 \longrightarrow d_0 + (u_1\bar{u}_1)$. The excited antiup quark further degenerates into a ground state up quark and a ground state up and antiup quark pair, $\bar{u}_1 \longrightarrow \bar{u}_0 + (u_0\bar{u}_0)$. The ground state antiup quark incompletely annihilates with the ground state down quark into an electron, $\bar{u}_0 + d_0 \longrightarrow e^-$. The ground state up and antiup quark pair completely annihilates into an electron antineutrino, $u_0 + \bar{u}_0 \longrightarrow \bar{\nu}_e$.

In the positron emission, an excited up quark in the positron after absorbing a certain amount of energy degenerates into a ground state up quark and produces an excited state down and antidown quark pair, energy + $u_1 \longrightarrow u_0 + (d_1\bar{d}_1)$. The excited antidown quark further degenerates into a ground state antidown quark and produces a ground state up and antiup quark pair, $\bar{d}_1 \longrightarrow \bar{d}_0 + (u_0\bar{u}_0)$. The ground state up quark incompletely annihilates with the ground state antidown quark to form a positron, $u_0 + \bar{d}_0 \longrightarrow e^+$. The ground state up and antiup quark pair completely annihilates into an electron neutrino, $u_0 + \bar{u}_0 \longrightarrow \nu_e$.

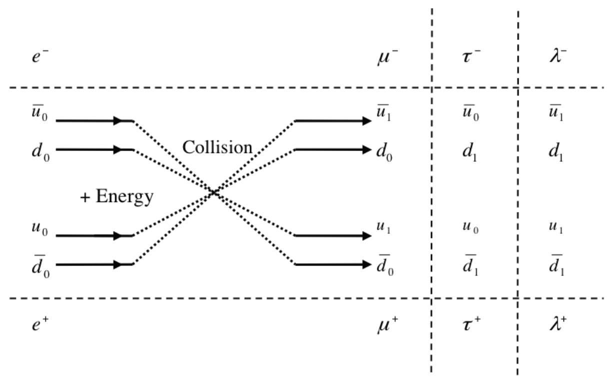

Fig. 3: Production of other three electrically charged leptons from an energetic electron-positron collision. In the collision, electron and positron are first disintegrated into quark-antiquark pairs, which are then excited and annihilated into other generations of electrically charge leptons.

The other three generations of electrically charged leptons can be produced by an energetic electron-positron collision,

$$\text{energy} + e^- + e^+ \longrightarrow \begin{cases} \mu^- + \mu^+ \\ \tau^- + \tau^+ \\ \lambda^- + \lambda^+ \end{cases}, \tag{1}$$

as also shown in Figure 3. In the particle physics, it has been experimentally shown that the energetic electron-positron collision can produce (μ^-, μ^+) and (τ^-, τ^+). But how the electron-positron collisions produce μ and τ leptons is still remained very poorly understood.

With the quark annihilation and pair production model proposed in this paper, we can understand why an electron-positron can produce μ and τ particles. In addition, we predict the existence of the fourth generation of leptons, λ particle and neutrino. The energetic electron-positron collision disintegrates the electron into a ground state antiup-down quark pair $e^- \longrightarrow (\bar{u}_0 d_0)$ and the positron into a ground state up-antidown quark pair $e^+ \longrightarrow (u_0\bar{d}_0)$. During the collision, the quarks and antiquarks in the disintegrated electron and positron quark-antiquark pairs absorb energy and become excited. The excited quark-antiquark pairs incompletely annihilate into another generation of electrically charged leptons.

There are three possible excitation patterns, which lead to three generations of leptons from the electron-positron collision. If the antiup quark in the disintegrated electron quark-antiquark pair and the up quark in the disintegrated positron quark-antiquark pair are excited, then the annihilations produce leptons μ^- and μ^+. If the down quark in the disintegrated electron quark-antiquark pair and the antidown quark in the disintegrated positron quark-antiquark pair are excited, then the annihilations produce leptons τ^- and τ^+. If both the antiup and down quarks in the disintegrated electron quark-antiquark pair and both the up and antidown quarks in the disintegrated positron quark-antiquark pair are excited, the annihilations produce the leptons λ^- and λ^+. An electron-positron collision in a different energy level produces a different generation of electrically charged leptons. To produce the λ particles, a more energetic electron-positron collision is required than μ and τ lepton productions. On the other hand, the electron and positron, if they are not disintegrated into quark-antiquark pairs during the collision, can directly annihilate into photons. The disintegrated electron and positron quark-antiquark pairs, if they are excited but not annihilated, can form the weak particles W^- and W^+.

A quark or antiquark can be excited when it absorbs energy or captures a photon. An excited quark or antiquark can degenerate into its corresponding ground state quark or antiquark after it releases a photon and/or one or more quark-antiquark pairs. The decays of these three generations of electrically charged leptons (μ, τ, and λ particles) can produce their corresponding neutrinos through degenerations and annihilations of quarks and antiquarks.

The currently discovered three generations of leptons including the fourth generation predicted in this paper are formed through the annihilations of the up and down quarks and antiquarks with an excited state. All these leptons are corresponding to or associated with the first generation of quarks and antiquarks. Considering the annihilations of other four flavor quarks and antiquarks, we can have many other types of leptons that are corresponding to the second and third generations of quarks and antiquarks. These leptons must be hardly generated and observed because a higher energy is required [4].

4 Quark Annihilation and Pair Production: Neutrino Oscillation

The complete (or type-II) annihilation between a quark and its corresponding antiquark forms a colorless and electrically neutral neutrino. On the contrary quark-antiquark annihilation, a neutrino, when it collides with a nucleon, may be disintegrated into a quark-antiquark pair. The disintegrated quark-antiquark pairs can be excited if it absorbs energy (e.g., $\gamma + u_0 \longrightarrow u_1$) and changed in flavor if it exchanges a weak particle (e.g., $u_0 + W^- \longrightarrow d_0$) during the disintegration. The excited and/or flavor changed quark-antiquark pair then either annihilates into another type of neutrino or interacts with the nucleon to form hadrons and electrically charged leptons. This provides a possible explanation for neutrino oscillations [19-20]. This scenario of neutrino oscillations does not need neutrinos to have mass and thus does not conflict with the standard model of particle physics.

Figure 4 and 5 show all possible oscillations among the four types of neutrinos. An electron neutrino can oscillate into a tau neutrino if the disintegrated quark-antiquark pair ($u_0\bar{u}_0$) is excited into ($u_1\bar{u}_1$) (Figure 4a), a muon neutrino if the disintegrated quark-antiquark pair ($u_0\bar{u}_0$) is changed in flavor into ($d_0\bar{d}_0$) (Figure 4b), and a lambda neutrino if the disintegrated quark-antiquark pair ($u_0\bar{u}_0$) is excited into ($u_1\bar{u}_1$) and then changed in flavor into ($d_1\bar{d}_1$) (Figure 4c). Similarly, A muon neutrino can oscillate into a tau neutrino if the disintegrated quark-antiquark pair ($d_0\bar{d}_0$) is excited and changed in flavor into ($u_1\bar{u}_1$) (Figure 5a) and a lambda neutrino if the disintegrated quark-antiquark pair ($d_0\bar{d}_0$) is excited and changed into ($d_1\bar{d}_1$) (Figure 5b). A tau neutrino can oscillate into a lambda neutrino if the disintegrated quark-antiquark pair ($u_1\bar{u}_1$) is changed in flavor into ($d_1\bar{d}_1$) (Figure 5c). All these oscillations described above are reversible processes. The right arrows in Figures 4 and 5 denote the neutrino oscillations when the disintegrated quark-antiquark pair absorbs energy to be excited or capture weak particles to be changed in flavor. Neutrinos can also oscillate when the disintegrated quark-antiquark pair emits energy and/or releases weak particles. In this cases, the right arrows in Figure 4 and 5 are replaced by left arrows and neutrinos oscillate from heavier ones to lighter ones.

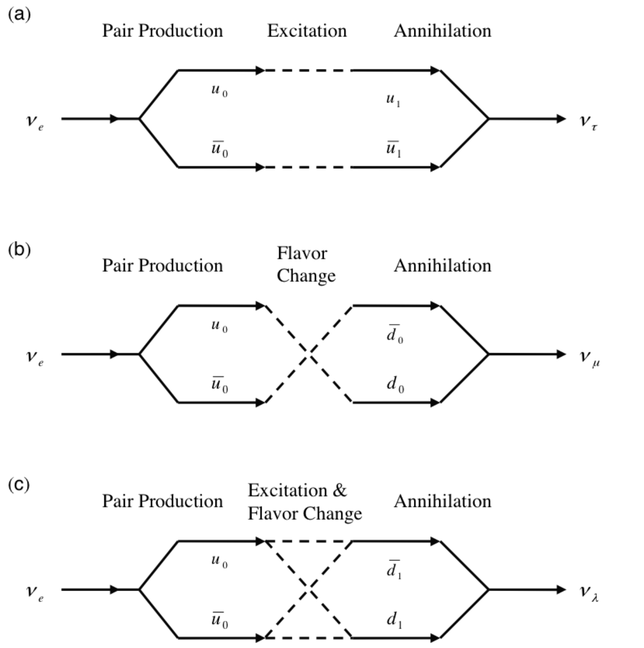

Fig. 4: Neutrino oscillations. (a) Oscillation between electron and tau neutrinos. (b) Oscillation between electron and muon neutrinos. (c) Oscillation between electron and lambda neutrinos.

The recent OPERA experiment at the INFN's Gran Sasso laboratory in Italy first observed directly a tau particle in a muon neutrino beam generated by pion and kaon decays and sent through the Earth from CERN that is 732 km away [21-23]. This significant result can be explained with a muon neutrino disintegration, excitation, and interaction with a nu-

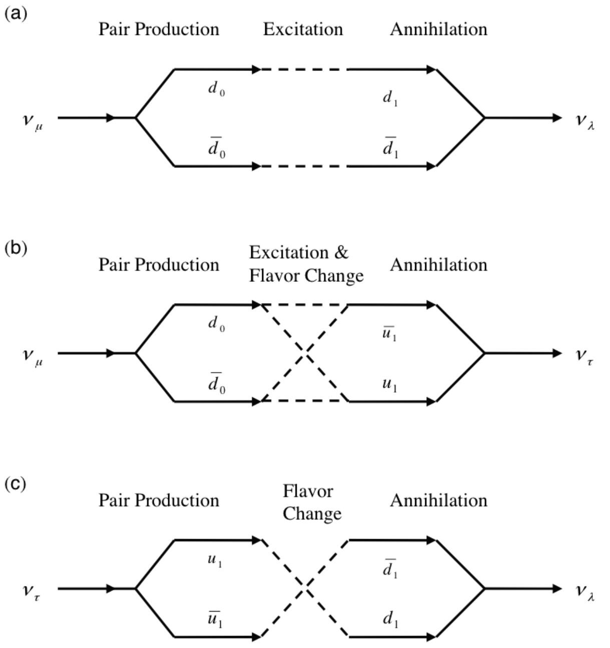

Fig. 5: Neutrino oscillations. (a) Oscillation between muon and lambda neutrinos. (b) Oscillation between muon and tau neutrinos. (c) Oscillation between tau and lambda neutrinos.

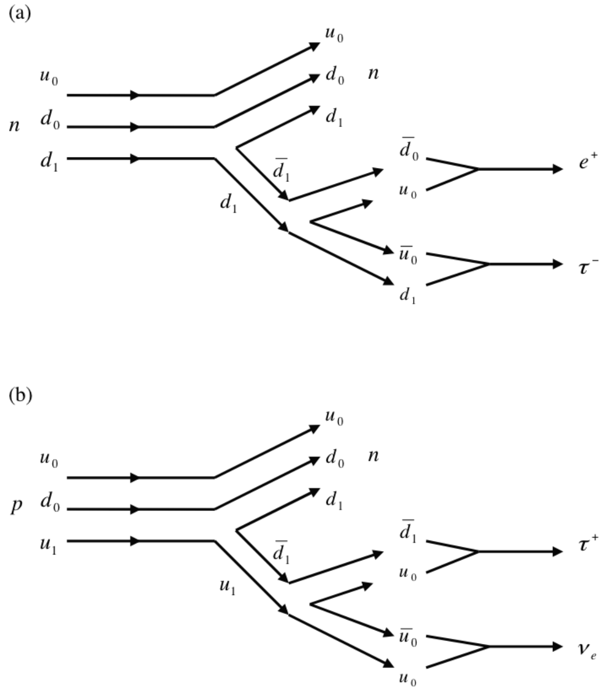

Fig. 6: Production of tau particles by a muon neutrino beam. (a) A negative tau particle is produced when an excited quark-antiquark pair, which is disintegrated from a muon neutrino and excited, interacts with a neutron. (b) A positive tau particle is produced when an excited quark-antiquark pair, which is disintegrated from a muon neutrino and excited, interacts with a proton.

cleon. Colliding with a neutron, a muon neutrino ν_μ is disintegrated into a ground state down-antidown quark pair ($d_0\bar{d}_0$), which can be excited into ($d_1\bar{d}_1$) and ($u_1\bar{u}_1$) when the flavor is also changed. The excited down-antidown quark pair ($d_1\bar{d}_1$) can either completely annihilate into a lambda neutrino ν_λ (Figure 5a) or interact with the neutron to generate a negative tau particle τ^- when the excited antidown quark degenerates into a ground state antidown and a ground state up-antiup quark pair, $\bar{d}_1 \longrightarrow \bar{d}_0 + (u_0\bar{u}_0)$ (Figure 6a). As shown in Figure 6a, the excited down quark in the neutron can incompletely annihilate with the ground state antiup quark into a negative tau particle τ^- and the ground state antidown quark can incompletely annihilate the ground state up quark into a positron e^+. Interacting with a proton (Figure 6b), the excited down-antidown quark pair ($d_1\bar{d}_1$) can generate a positive tau particle τ^+ when the excited up quark in the proton degenerates into a ground state up quark and a ground state up-antiup quark pair, $u_1 \longrightarrow u_0 + (u_0\bar{u}_0)$. The excited antidown quark can incompletely annihilate with the ground state up quark into a positive tau particle τ^+ and the ground state antiup quark can completely annihilate with the ground state up quark into an electron neutrino ν_e. If the excited up quark is not degenerated but directly annihilate with the excited antidown quark, a lambda particle λ^+ is produced (as shown in Figure 3).

On the other hand, for an electron neutrino beam, colliding with a nucleon, an electron neutrino ν_e is disintegrated into a ground state up-antiup quark pair ($u_0\bar{u}_0$) and excited into ($u_1\bar{u}_1$), which may be also from the disintegration of a muon neutrino with the favor change. This excited up-antiup quark-antiquark pair can either completely annihilate into a tau neutrino as shown in Figure 1 or interact with the nucleon to generate a muon particle (Figure 7). If the flavor is also changed, the annihilation and interaction with nucleons will produce the tau particles and neutrinos as shown in Figure 6 or lambda particles and neutrinos as shown in Figure 3.

Therefore, with the lepton formation and quark-antiquark pair production model developed in this paper, we can understand the recent measurement of a tau particle in a muon neutrino beam as well as the early measurements of muon particles in electron neutrino beams. More future experiments of the Large Electron-Positron Collider at CERN and measurements of neutrino oscillations are expected to validate this lepton formation and quark-antiquark pair production model and detect the fourth generation of leptons.

5 Conclusions

This paper develops a quark-antiquark annihilation and pair production model to explain the formation of leptons and the oscillation of neutrinos and further predict the fourth generation of leptons named as lambda particle and neutrino. It

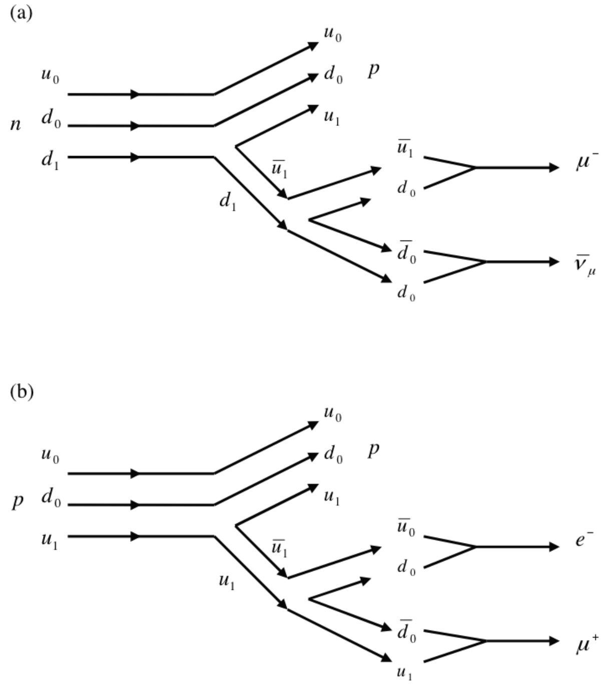

Fig. 7: Production of muon particles by an electron neutrino beam. (a) A negative muon particle is produced when an excited up-antiup quark pair, which is disintegrated from an electron neutrino and excited, interacts with a neutron. (b) A positive tau particle is produced when an excited quark-antiquark pair, which is disintegrated from a muon neutrino and excited, interacts with a proton.

is well known that all known or discovered leptons can be formed or emerged from particles or hadrons that are composed of only up and down quarks. This fact indicates that leptons must be consequences of activities of the up and down quarks and antiquarks. As quarks contain color charges, they participate in the strong interaction. Leptons do not contain color charges so that they do not participate in the strong interaction. In this paper, we suggested that all leptons are formed from quark-antiquark annihilations. There are two types of quark-antiquark annihilations. Type-I quark-antiquark annihilation annihilates only color charges, which forms structueless and colorless but electrically charged leptons such as electron, muon, tau, and lambda particles. Type-II quark-antiquark annihilation annihilates both electric and color charges, which forms structureless, colorless, and electrically neutral leptons such as electron, muon, tau, and lambda neutrinos. For the two types (up and down) of quarks and antiquarks to generate all four generation leptons from annihilations, they must have at least one excited state. Analyzing these two types of annihilations between up and down quarks and antiquarks with one excited quantum state for each of them, we predict the formation of the fourth generation of leptons named lambda particle and lambda neutrino. On the other hand, a lepton, when it collides with a nucleon, can be disintegrated into a quark-antiquark pair, which can be exited and/or changed in flavor. The quark-antiquark pair disintegrated from a neutrino can be excited and/or changed in flavor during the collision and then annihilate into another type of neutrino or interact with a nucleon to form electrically charged leptons. This quark-antiquark annihilation and pair production model provides a possible explanation for neutrino oscillations without hurting the standard model of particle physics. With it, we can understand the recent OPERA measurement of a tau particle in a muon neutrino beam as well as the early measurements of muon particles in electron neutrino beams.

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