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The Mechanism of the Particle–Antiparticle Pair Annihilation

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Abstract

New interpretation of the spacetime axis is suggested in view of the special relativity. We can consider that the real world we live in is the complex 4-dimensional spacetime world which is formed by the real visible 3-dimensional space components (so-called, space axis) and by the imaginary invisible 1-dimensional space component (so-called, time axis), at the real 4-dimensional space axis. Time is the imaginary 1-dimensional vector at the real space axis in the spacetime axis. Energy is the imaginary 1-dimensional momentum vector at the real space axis in the spacetime axis. Rest mass plays an essential role in forming of stable spacetime world. The destabilization of the spacetime in energy because of the zero value of the total imaginary momentum as a consequence of the contact between the particle and antiparticle is the reason why an antiparticle can annihilate a particle.

Keywords: *Spacetime Axis; Special Relativity; Imaginary 1-Dimensional Time Vector; Imaginary 1-Dimensional Energy Vector; The Mechanism of the Particle–Antiparticle Annihilation; Zero Time Momentum Vector.*

1. Introduction

The effect of vibronic interactions and electron–phonon interactions [1–7] in molecules and crystals is an important topic of discussion in modern chemistry and physics. The vibronic and electron–phonon interactions play an essential role in various research fields such as the decision of molecular structures, Jahn–Teller effects, Peierls distortions, spectroscopy, electrical conductivity, and superconductivity. We have investigated the electron–phonon interactions in various charged molecular crystals for more than 15 years [1–8]. In particular, in 2002, we predicted the occurrence of superconductivity as a consequence of vibronic interactions in the negatively charged picene, phenanthrene, and coronene [8]. Recently, it was reported that these trianionic molecular crystals exhibit superconductivity [9].

Related to the research of superconductivity as described above, in the recent research [10,11], we explained the mechanism of the Ampère's law (experimental rule discovered in 1820) and the Faraday's law (experimental rule discovered in 1831) in normal metallic and superconducting states [12], on the basis of the theory suggested in our previous researches [1–7]. Furthermore, we discussed how the left-handed helicity magnetic field can be induced when the negatively charged particles such as electrons move [13]. That is, we discussed the relationships between the electric and magnetic fields [13]. Furthermore, by comparing the electric charge with the spin magnetic moment and mass, we suggested the origin of the electric charge in a particle. Furthermore, in the previous research, we discussed the origin of the gravity, by comparing the gravity with the electric and magnetic forces. Furthermore, we showed the reason why the gravity is much smaller than the electric and magnetic forces [14]. We discussed the origin of the strong forces, by comparing the strong force with the gravitational, electric, magnetic, and electromagnetic forces. We also discussed the essential properties of the gluon and color charges, and discussed the reason why the quarks and gluons are confined in hadron [15]. Furthermore, we discussed the origin of the weak forces, and discussed the reason why the parity violation can be observed in the weak interactions [16]. We also suggested the relationships between the Cooper pairs in superconductivity and the Higgs boson in the vacuum [16,17]. Recently, we discussed the origin of the spin magnetic dipole moment, massive charge, electric monopole charge, and color charge for the particle and antiparticles at the particles and antiparticle spacetime axes, by considering that particles (antiparticles) can be formed by mixture of the wavefunction of more dominant particle (antiparticle) component and of less dominant antiparticle (particle) component [18].

In this research, we will suggest the new interpretation of the spacetime axis in the special relativity. We will also discuss the mechanism of the particle–antiparticle pair annihilation in view of the special relativity.

2. New Interpretation of the Spacetime Axis in the Special Relativity

In this article, we define the spacetime components of the particles and antiparticles as follows (Figs. 1 and 2).

The $\boldsymbol{r}_{\boldsymbol{r}_{\mathrm{p}}}$ and $\boldsymbol{r}_{\boldsymbol{r}_{\mathrm{a}}}$ terms denote the real space components at the real 3-dimensional real space axis for particles and antiparticles, respectively. The $\boldsymbol{r}_{t_\mathrm{p}}$ and $\boldsymbol{r}_{t_\mathrm{a}}$ terms denote the real space components at the real 3-dimensional time axis for particles and antiparticles, respectively.

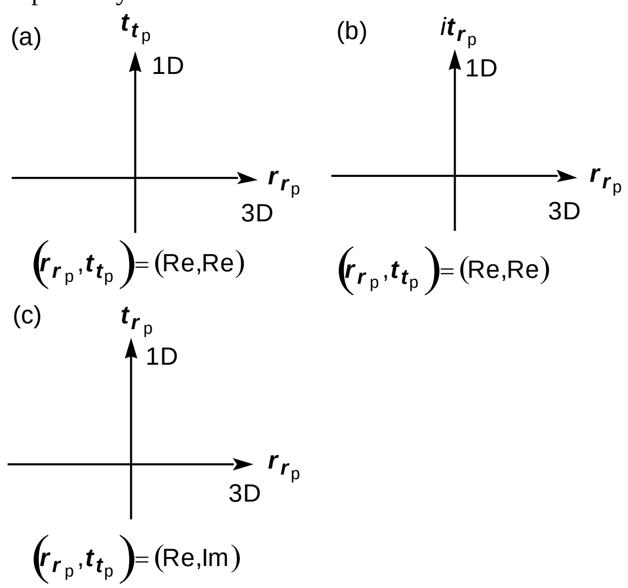

Fig. 1. Relationships between the space and time axes. (a) The 3-dimensional real space axis and the 1-dimensional real time axis. (b) The 3-dimensional real space axis and the 1-dimensional imaginary space axis. (c) The 3-dimensional real space axis and the 1-dimensional real space axis.

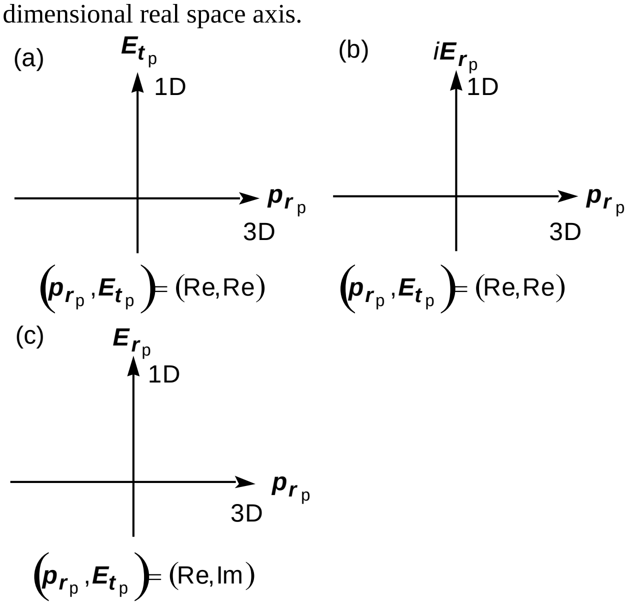

Fig. 2. Relationships between the momentum and energy axes. (a) The 3-dimensional real momentum axis and the 1-dimensional real energy axis. (b) The 3-dimensional real momentum axis and the 1-dimensional imaginary momentum axis. (c) The 3-dimensional real momentum axis and the 1-dimensional real momentum axis.

The $\boldsymbol{t}_{t_\mathrm{p}}$ and $\boldsymbol{t}_{t_\mathrm{a}}$ terms denote the real time components at the real 1-dimensional time axis for particles and antiparticles, respectively. The $\boldsymbol{t}_{r_\mathrm{p}}$ and $\boldsymbol{t}_{r_\mathrm{a}}$ terms denote the real time components at the real 1-dimensional space axis for particles and antiparticles, respectively.

The $\boldsymbol{p}_{r_\mathrm{p}}$ and $\boldsymbol{p}_{r_\mathrm{a}}$ terms denote the real momentum components at the real 3-dimensional space axis for particles and antiparticles, respectively. The $\boldsymbol{p}_{t_\mathrm{p}}$ and $\boldsymbol{p}_{t_\mathrm{a}}$ terms denote the real momentum components at the real 3-dimensional time axis for particles and antiparticles, respectively.

The $\boldsymbol{E}_{t_\mathrm{p}}$ and $\boldsymbol{E}_{t_\mathrm{a}}$ terms denote the real energy components at the real 1-dimensional time axis for particles and antiparticles, respectively. The $\boldsymbol{E}_{r_\mathrm{p}}$ and $\boldsymbol{E}_{r_\mathrm{a}}$ terms denote the real energy components at the real 1-dimensional space axis for particles and antiparticles, respectively.

2.1 Momentum and Energy at the Real Space and Imaginary Time Axes in the Spacetime Axis

According to the special relativity and Minkowski's research, the relationships between the space (x, y, z) and time axes (t) can be expressed as

$$x^2 + y^2 + z^2 + (ict)^2 = \text{const}. \qquad (1)$$

where the c is the speed of the light.

In other words,

$$\boldsymbol{r}_{r_\mathrm{p}}^2 + \left(c\boldsymbol{t}_{t_\mathrm{p}}\right)^2 = \text{const}. \qquad (2)$$

$$\boldsymbol{r}_{r_\mathrm{a}}^2 + \left(c\boldsymbol{t}_{t_\mathrm{a}}\right)^2 = \text{const}. \qquad (3)$$

On the other hand, the 1-dimensional $\boldsymbol{t}_{t_\mathrm{p}}$ and $\boldsymbol{t}_{t_\mathrm{a}}$ time vectors, which are real components at the real time axis, are the imaginary components at the real 1-dimensional space axis, as expressed as (Fig. 1 (c)),

$$\boldsymbol{t}_{t_\mathrm{p}} = i\boldsymbol{t}_{r_\mathrm{p}}, \qquad (4)$$

$$\boldsymbol{t}_{t_\mathrm{a}} = i\boldsymbol{t}_{r_\mathrm{a}}. \qquad (5)$$

Therefore,

$$\boldsymbol{r}_{r_\mathrm{p}}^2 + \left(c\boldsymbol{t}_{t_\mathrm{p}}\right)^2 = \boldsymbol{r}_{r_\mathrm{p}}^2 + \left(ic\boldsymbol{t}_{r_\mathrm{p}}\right)^2 = \text{const}. \qquad (6)$$

$$\boldsymbol{r}_{\boldsymbol{r}_\mathrm{a}}^2 + \left(c\boldsymbol{t}_{\boldsymbol{t}_\mathrm{a}}\right)^2 = \boldsymbol{r}_{\boldsymbol{r}_\mathrm{a}}^2 + \left(ic\boldsymbol{t}_{\boldsymbol{r}_\mathrm{a}}\right)^2 = \mathrm{const.} \qquad (7)$$

If we consider that we live in the real visible space axis, real time axis ($\boldsymbol{t}_{\boldsymbol{t}_\mathrm{p}}$ and $\boldsymbol{t}_{\boldsymbol{t}_\mathrm{a}}$) can be considered to be imaginary invisible space axis ($i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$ and $i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{a}}$) (Fig. 1 (b)). That is, we can consider that the ct term is related to the real time component (imaginary space component) (Fig. 1 (a)), on the other hand, the ict term is related to the real space component (imaginary time component) (Fig. 1 (b)).

Therefore, we can consider that the real world we live in is the complex 4-dimensional spacetime world which is formed by the real visible 3-dimensional space components (so-called, space axis) and by the imaginary invisible 1-dimensional space component (so-called, time axis), at the real 4-dimensional space axis (Fig. 1 (c)).

The 4-dimensional spacetime axis can be interpreted by various definitions as follows. The components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and of the 1-dimensional real time vectors at the 1-dimensional real time axis (Fig. 1 (a)). The components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and the 1-dimensional real time vectors at the 1-dimensional imaginary space axis (Fig. 1 (b)). The components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and of the 1-dimensional imaginary time vectors at the 1-dimensional real space axis (Fig. 1 (c)). In the discussion in this article, we will use the definition that the components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and of the 1-dimensional imaginary time vectors at the 1-dimensional real space axis (Fig. 1 (c)).

From Eqs. (6) and (7), denoting the relationships between the space and time axes, we can derive the equation, denoting the relationships between the momentum (p_x, p_y, p_z, p_t, $p_{t,0}$) and energy (E_x, E_y, E_z, E_t, $E_{t,0}$) by using the mass q_g and the rest mass $q_{\mathrm{g},0}$, as follows (Fig. 2),

$$\left(q_\mathrm{g}v_x\right)^2 + \left(q_\mathrm{g}v_y\right)^2 + \left(q_\mathrm{g}v_z\right)^2 + \left(iq_\mathrm{g}c\right)^2 = \left(iq_{\mathrm{g},0}c\right)^2 = \mathrm{const.} < 0, \qquad (8)$$

$$p_x^2 + p_y^2 + p_z^2 + p_t^2 = p_{t,0}^2 = \mathrm{const.} < 0, \qquad (9)$$

$$p_x^2 + p_y^2 + p_z^2 + \left(\frac{E_t}{c}\right)^2 = \left(\frac{E_{t,0}}{c}\right)^2 = \mathrm{const.} < 0, \qquad (10)$$

where

$$p_x = q_\mathrm{g}v_x, \qquad (11)$$

$$p_y = q_\mathrm{g}v_y, \qquad (12)$$

$$p_z = q_\mathrm{g}v_z, \qquad (13)$$

$$p_t = iq_\mathrm{g}c, \qquad (14)$$

$$p_{t,0} = iq_{\mathrm{g},0}c, \qquad (15)$$

$$E_t = cp_t, \qquad (16)$$

$$E_{t,0} = cp_{t,0}. \qquad (17)$$

In other words (Fig. 2 (a)),

$$\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}^2 + \boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}}^2 = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}^2 + \left(\frac{\boldsymbol{E}_{\boldsymbol{t}_\mathrm{p}}}{c}\right)^2 = \left(\frac{\boldsymbol{E}_{\boldsymbol{t}_\mathrm{p},0}}{c}\right)^2 = \mathrm{const.} \qquad (18)$$

$$\boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}^2 + \boldsymbol{p}_{\boldsymbol{t}_\mathrm{a}}^2 = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}^2 + \left(\frac{\boldsymbol{E}_{\boldsymbol{t}_\mathrm{a}}}{c}\right)^2 = \left(\frac{\boldsymbol{E}_{\boldsymbol{t}_\mathrm{a},0}}{c}\right)^2 = \mathrm{const.} \qquad (19)$$

where

$$\boldsymbol{E}_{\boldsymbol{t}_\mathrm{p}} = c\boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}}, \qquad (20)$$

$$\boldsymbol{E}_{\boldsymbol{t}_\mathrm{a}} = c\boldsymbol{p}_{\boldsymbol{t}_\mathrm{a}}. \qquad (21)$$

On the other hand, the 1-dimensional $\boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}}$ and $\boldsymbol{p}_{\boldsymbol{t}_\mathrm{a}}$ ($\boldsymbol{E}_{\boldsymbol{t}_\mathrm{p}}$ and $\boldsymbol{E}_{\boldsymbol{t}_\mathrm{a}}$) momentum (energy) vectors, which are real components at the time axis, are the imaginary components at the real 1-dimensional space axis, as expressed as (Fig. 2 (b), (c)),

$$\boldsymbol{E}_{\boldsymbol{t}_\mathrm{p}} = i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}, \qquad (22)$$

$$\boldsymbol{E}_{\boldsymbol{t}_\mathrm{a}} = i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}. \qquad (23)$$

Therefore, the $\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}$ and $\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}$ can be interpreted as the energy momentum vector for the particles and antiparticles, respectively (Fig. 2 (c)). Eq. (10) can be expressed by using vectors as (Fig. 2 (c))

$$\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}^2 + \boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}}^2 = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}^2 + \left(\frac{\boldsymbol{E}_{\boldsymbol{t}_\mathrm{p}}}{c}\right)^2 = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}^2 + \left(\frac{i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}}{c}\right)^2 = \left(\frac{i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p},0}}{c}\right)^2 = \text{const.} \quad (24)$$

$$\boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}^2 + \boldsymbol{p}_{\boldsymbol{t}_\mathrm{a}}^2 = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}^2 + \left(\frac{\boldsymbol{E}_{\boldsymbol{t}_\mathrm{a}}}{c}\right)^2 = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}^2 + \left(\frac{i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}}{c}\right)^2 = \left(\frac{i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a},0}}{c}\right)^2 = \text{const.} \quad (25)$$

The momentum p_x, p_y, and p_z values are related to the real components at the real space axis, x, y, and z, respectively. The energy E_t is related to the real (imaginary) component at the real time (real space) axis (Fig. 2 (a)). The p_t and $p_{t,0}$ (E_t / c and $E_{t,0} / c$) terms are usually considered to be related to the energy, that is, related to the real components at the time axis (Fig. 2 (a)). On the other hand, if we consider that we live in the real visible momentum axis, which is related to the real space axis, the energy can be considered to be the imaginary invisible momentum component at the real space axis (Fig. 2 (b), (c)). Therefore, we can consider that the p_t and E_t terms, and the $p_{t,0}$ and $E_{t,0}$ terms, are related to the real time component (imaginary space component), on the other hand, the ip_t and iE_t terms, and the $ip_{t,0}$ and $iE_{t,0}$ terms, are related to the real space component (imaginary time component).

Let us next express the energy components from Eqs. (24) and (25),

$$E_x^2 + E_y^2 + E_z^2 + E_t^2 = E_{t,0}^2 = \text{const.} < 0, \quad (26)$$

$$\sqrt{-\left(E_x^2 + E_y^2 + E_z^2 + E_t^2\right)} = \sqrt{-E_{t,0}^2}, \quad (27)$$

where

$$E_x = cp_x, \quad (28)$$

$$E_y = cp_y, \quad (29)$$

$$E_z = cp_z, \quad (30)$$

$$\sqrt{-\left\{\left(c\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}\right)^2 + \left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}\right)^2\right\}} = \sqrt{-\left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p},0}\right)^2}, \quad (31)$$

$$\sqrt{-\left\{\left(c\boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}\right)^2 + \left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}\right)^2\right\}} = \sqrt{-\left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a},0}\right)^2}, \quad (32)$$

$$\left(c\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}\right)^2 + \left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}\right)^2 = \left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p},0}\right)^2, \quad (33)$$

$$\left(c\boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}\right)^2 + \left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}\right)^2 = \left(i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a},0}\right)^2. \quad (34)$$

We can see from Eqs. (33) and (34) that the original point ($p_x = p_y = p_z = p_t = 0$) at the spacetime axis in energy is saddle point (massless transition state (TS)) [19] of the converting reaction between massive particle and antiparticle states in momentum-energy curves (Fig. 3). The original point ($p_x = p_y = p_z = p_t = 0$) is the minimum point in energy at the p_x, p_y, and p_z axes ($p_x = p_y = p_z = 0$) (Fig. 3 (a), (c)), on the other hand, that is the maximum point in energy at the real space axis at the p_t axis ($p_t = 0$) (Fig. 3 (d)). Therefore, the space can be considered to be real components (reversible) of the space axis at the spacetime axis (Fig. 3 (c)). On the other hand, the time can be considered to be the imaginary components (irreversible) of the space axis at the spacetime axis (Fig. 3 (d)). That is, the 3-dimensional space components are real components in the real 3-dimensional space axis, and the 1-dimensional time components are the imaginary components in the 1-dimensional real space axis (Fig. 1 (c)).

The original point of the space axis at the spacetime axis is the bottom point, and the most stable in energy (Fig. 3 (c)). Therefore, only small energy is needed for space to reverse at the real space axis. Therefore, the reversible process from the $+\boldsymbol{r}_{\boldsymbol{r}_\mathrm{p}}$ to the $-\boldsymbol{r}_{\boldsymbol{r}_\mathrm{p}}$ (from the $+\boldsymbol{r}_{\boldsymbol{r}_\mathrm{a}}$ to the $-\boldsymbol{r}_{\boldsymbol{r}_\mathrm{a}}$) can be possible (Fig. 3 (a), (c)), and we can observe the real space axis, visibly. This is the reason why momentum vectors $\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}}$ and $\boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}}$, and related space axis $\boldsymbol{r}_{\boldsymbol{r}_\mathrm{p}}$ and $\boldsymbol{r}_{\boldsymbol{r}_\mathrm{a}}$, are the 3-dimensional real vectors at the real space axis (Figs. 1 (a) and 2 (a)).

The time can be considered to be the imaginary components (irreversible) of the space axis at the spacetime axis (Fig. 1 (c)). The original point of the time at the real space axis is the top point, and the most unstable in energy (Fig. 3 (b), (d)). Therefore, very large energy is needed for the time to reverse at the real space axis. Therefore, the reversible process from the future $+\boldsymbol{t}_{\mathrm{p}}$ ($+i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$) to the past $-\boldsymbol{t}_{\mathrm{p}}$ ($-i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$) (from the future $+\boldsymbol{t}_{\mathrm{a}}$

($+it_{r_a}$) to the past $-t_{t_a}$ ($-it_{r_a}$)) cannot be possible, furthermore, we cannot observe the real time (imaginary components) at the real space axis, visibly (Fig. 3 (b)). This is the reason why the energy E_{t_p} ($=iE_{r_p}$) and E_{t_a} ($=iE_{r_a}$), and related time axis t_{t_p} ($=it_{r_p}$) and t_{t_a} ($=it_{r_a}$), are considered to be not vector but scalar. On

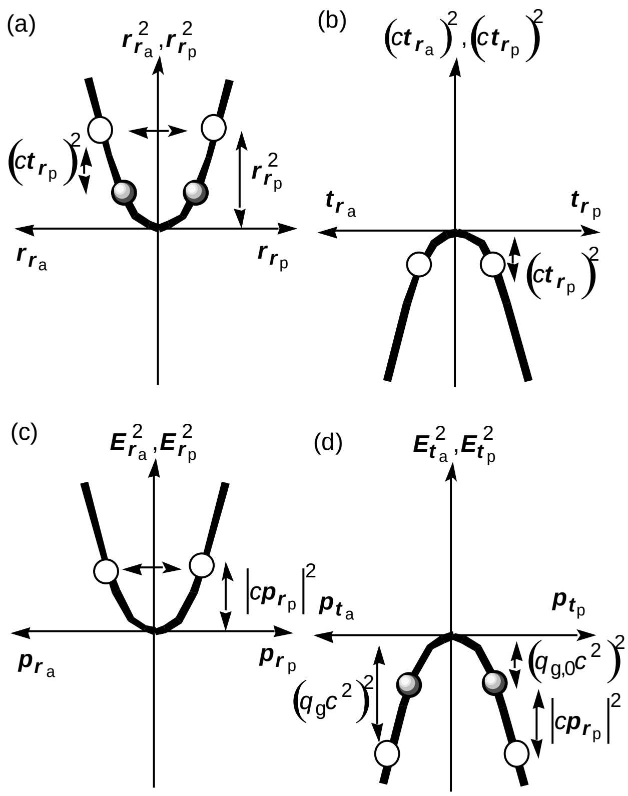

Fig. 3. (a) Scale of the space. The opened and shaded circles indicate the scales of the space and the total spacetime, respectively. (b) Scale of the time denoted by the opened circles. (c) Energy for the space axis denoted by the opened circles. (d) Energy for the time axis. The opened and shaded circles indicate the energies of the time and the total spacetime axes, respectively.

the other hand, we can interpret that the energy vectors E_{t_p} ($=iE_{r_p}$) and E_{t_a} ($=iE_{r_a}$), and related time axis t_{t_p} ($=it_{r_p}$) and t_{t_a} ($=it_{r_a}$), are the 1-dimensional imaginary vectors at the real space axis (Figs. 1 (c) and 2 (c)).

Particles and antiparticles have intrinsic r_{r_p} - it_{r_p} and r_{r_a} - it_{r_a} spacetime axes, respectively. Particles and antiparticles cannot be usually distinguished by each other by reversible space axis (r_{r_p} and p_{r_p}, and r_{r_a} and p_{r_a}) (Fig. 3 (a), (c)). On the other hand, particles and antiparticles can be usually distinguished by each other by irreversible time axis (it_{r_p} and iE_{r_p}, and it_{r_a} and iE_{r_a}) (Fig. 3 (b), (d)). The dominance of particles rather than antiparticles is the reason why we live only from the past ($-t_{t_p}$ ($-it_{r_p}$)) to the future ($+t_{t_p}$ ($+it_{r_p}$)) in the real particle space axis (Fig. 3 (b)).

In summary, the space axis is the real 3-dimensional space vector in the spacetime axis (Fig. 1 (c)). Momentum is the real 3-dimensional momentum vector at the real space axis in the spacetime axis (Fig. 2 (c)). The time is the imaginary 1-dimensional space vector at the real space axis in the spacetime axis (Fig. 1 (c)). The energy is the imaginary 1-dimensional momentum vector at real space axis in the spacetime axis (Fig. 2 (c)).

2.2 Relationships between the Rest Mass and Stability of the Spacetime

Let us next look into the relationships between the rest mass and the stability of the spacetime. As an example, we consider a particle. The relationship between the rest mass energy ($E_{t,0}^2$) and the energy for spacetime ($E_x^2+E_y^2+E_z^2+E_t^2$) can be expressed as

$$E_x^2+E_y^2+E_z^2+E_t^2=E_{t,0}^2\leq 0, \quad (35)$$

or

$$E_{r_p}^2+E_{t_p}^2=E_{t_p,0}^2\leq 0, \quad (36)$$

where

$$E_{r_p}^2\geq 0, \quad (37)$$

$$E_{t_p}^2\leq 0, \quad (38)$$

$$E_{t_p,0}^2\leq 0. \quad (39)$$

The E_{t_p} ,and $E_{t_p,0}$ values are related to the p_{t_p} and $p_{t_p,0}$ values, respectively.

The E_{t_p} value, related to the time traveling velocity $+\Delta t_{t_p}$, becomes equal to the rest mass energy $q_{g,0}c^2$ value when the p_x, p_y, and p_z values, related to the space axis, are 0, as follows (Fig. 4 (a)),

$$\lim_{p_x,p_y,p_z\to 0} p_t^2=p_{t,0}^2=\left(iq_{g,0}c\right)^2. \quad (40)$$

Therefore, the time traveling velocity $+\Delta \boldsymbol{t}_{t_{\text{p}}}$ is related to the rest mass $q_{\text{g},0}$ value. Furthermore, the time traveling velocity $+\Delta \boldsymbol{t}_{t_{\text{p}}}$ is related to the electric charge q_{e} as well as the rest mass $q_{\text{g},0}$, which are generated as a consequence of the Higgs mechanism.

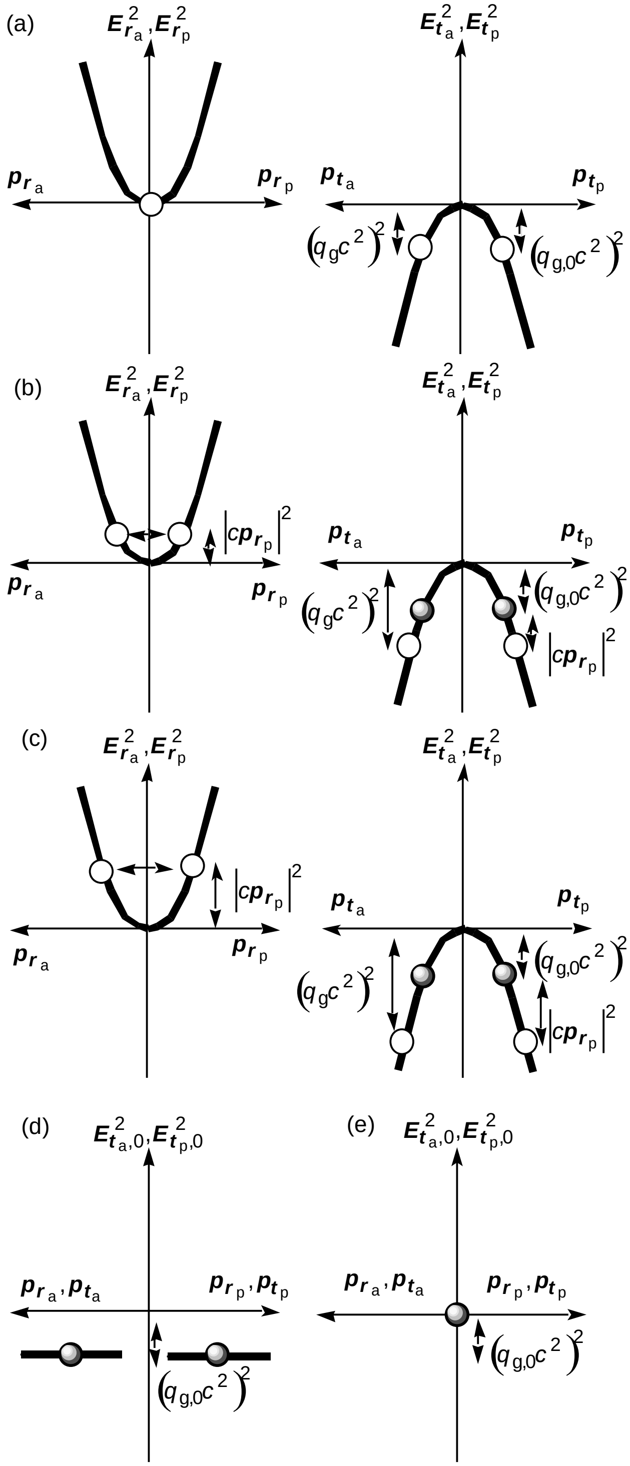

Fig. 4. Energies as a function of the space and time. (a)–(c) Energies for the space and time axes. (d)–(e) Total energies for the spacetime axis. In (a)–(e), the opened circles denote the energies for the the space and time axes. The shaded circles indicate the total energy for the spacetime axis.

We can see from Eq. (24) that the $\left|\boldsymbol{p}_{t_{\text{p}}}\right|$ value increases with an increase in the $\left|\boldsymbol{p}_{r_{\text{p}}}\right|$ value. That is, the stabilization energy $\left|\boldsymbol{E}_{t_{\text{p}}}\right|$ value increases with an increase in the destabilization energy $\left|\boldsymbol{E}_{r_{\text{p}}}\right|$ value so that the total stabilization energy $\left|\boldsymbol{E}_{t_{\text{p}},0}\right|$ value in the space world becomes constant (Fig. 4 (a)–(d)). That is, the total spacetime energy ($\left|\boldsymbol{E}_{t_{\text{p}},0}\right|$) originating from the space axis ($\left|\boldsymbol{E}_{r_{\text{p}}}\right|$) and the time axis ($\left|\boldsymbol{E}_{t_{\text{p}},0}\right|$) try to become always constant by distortion of the spacetime (Fig. 4 (d)). At the same time, the scale of the space $\Delta \boldsymbol{r}_{r_{\text{p}}}$ and the time traveling velocity $\Delta \boldsymbol{t}_{t_{\text{p}}}$ decreases with an increase in the $\boldsymbol{p}_{r_{\text{p}}}$ value. Spacetime becomes very unstable in energy if the $\boldsymbol{p}_{t_{\text{p}}}$ value becomes 0 (Fig. 4 (e)). That is, the time traveling velocity $\Delta \boldsymbol{t}_{t_{\text{p}}}$ and imaginary time momentum vector $\boldsymbol{p}_{t_{\text{p}}}$ at the real space axis (momentum at the time axis), related to the rest mass $q_{\text{g},0}$, play an essential role in the forming of the stable real spacetime world we live in (Fig. 4). Similar discussion can be made in the case of the antiparticles.

Furthermore, the time traveling velocity can be decided by the rest mass $q_{\text{g},0}$ of particle or antiparticle at $p_x = p_y = p_z = 0$. The rest mass $q_{\text{g},0}$ of particle and antiparticle plays an essential role in the forming of the stable spacetime world for particles and antiparticles, respectively (Fig. 4 (d)). The stabilization energy for the spacetime increases with an increase in the rest mass $q_{\text{g},0}$ (Fig. 4).

3. Particle–Antiparticle Pair Annihilation

As described above, components at the 4-dimensional spacetime axis are composed from the real 3-dimensional components and the imaginary 1-dimensional components at the 4-dimensional real space axis. The momentum ($\boldsymbol{p}_{r_{\text{p}}}$ and $\boldsymbol{p}_{r_{\text{a}}}$) has been considered to be related to the real space axis ($\boldsymbol{r}_{r_{\text{p}}}$ and $\boldsymbol{r}_{r_{\text{a}}}$), and the energy ($\boldsymbol{E}_{t_{\text{p}}}$ and $\boldsymbol{E}_{t_{\text{a}}}$) has been considered to be related to the time axis

($\boldsymbol{t}_{t_\mathrm{p}}$ and $\boldsymbol{t}_{t_\mathrm{a}}$). On the other hand, we can also define the imaginary 1-dimensional momentum vector ($i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}$ and $i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}$) at the real space axis ($\boldsymbol{r}_{r_\mathrm{p}}$ and $\boldsymbol{r}_{r_\mathrm{a}}$). Energy vector ($\boldsymbol{E}_{t_\mathrm{p}}$ and $\boldsymbol{E}_{t_\mathrm{a}}$) is the real vector at the real time axis (imaginary space axis), on the other hand, is the imaginary momentum vector ($\boldsymbol{p}_{t_\mathrm{p}}$ ($= i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}/c$) and $\boldsymbol{p}_{t_\mathrm{a}}$ ($= i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}/c$)) at the real space axis. This is the reason why the energy can be considered to be not the vector but the scalar at the real time axis. On the other hand, we can define that the energy is the imaginary momentum vector ($\boldsymbol{p}_{t_\mathrm{p}}$ ($= i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{p}}/c$) and $\boldsymbol{p}_{t_\mathrm{a}}$ ($= i\boldsymbol{E}_{\boldsymbol{r}_\mathrm{a}}/c$)) at the real space axis (the imaginary time axis). The $\boldsymbol{E}_{t_\mathrm{p}}$ value for particle and the $\boldsymbol{E}_{t_\mathrm{a}}$ value for the corresponding antiparticle are the same in quantity, but opposite in direction in the time axis. Time has been considered to be not vector but scalar. On the other hand, we can consider that the time is the imaginary 1-dimensional vector ($\boldsymbol{t}_{t_\mathrm{p}}$ ($= i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$) and $\boldsymbol{t}_{t_\mathrm{a}}$ ($= i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{a}}$)) at the real space axis. The time traveling velocity $\Delta\boldsymbol{t}_{t_\mathrm{p}}$ ($= i\Delta\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$) value for particle and the $\Delta\boldsymbol{t}_{t_\mathrm{a}}$ ($= i\Delta\boldsymbol{t}_{\boldsymbol{r}_\mathrm{a}}$) value for the corresponding antiparticle are the same in quantity, but opposite in the direction at the real time axis.

On the basis of the discussions in the previous section, let us discuss the mechanism of the particle-antiparticle pair annihilation. In particle physics, antimatter is a material composed of antiparticles, which have the same mass as particles of ordinary but opposite charges. Collisions between particles and antiparticles lead to the annihilation of both, giving rise to variable properties of intense photons (gamma rays), neutrinos, and less massive particle–antiparticle pairs. The total consequence of annihilation is a release of energy available for work, proportional to the total matter and antimatter mass, in accord with the mass-energy equivalence equation, $E = q_\mathrm{g}c^2$. The Feynman–Stueckelberg interpretation states that antimatter and antiparticles are regular particles traveling backward in time.

Positrons ($\bar{e}$) are regular electrons (e) traveling backward in time. In the real world we live, where time travels from the past to the future ($+\boldsymbol{t}_{t_\mathrm{p}}$ ($= +i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$)) at the particle time axis ($\boldsymbol{t}_{t_\mathrm{p}}$ ($= i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$), positrons are usually observed to have positive charge and travels from the past to the future ($+\boldsymbol{t}_{t_\mathrm{p}}$ ($= +i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$)) at the particle time axis ($\boldsymbol{t}_{t_\mathrm{p}}$ ($= i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$)). It should be noted that such positively charged antiparticle with $\boldsymbol{p}_{t_\mathrm{a}}$, which behaves as if it is a particle traveling from the past to the future ($+\boldsymbol{t}_{t_\mathrm{p}}$ ($= +i\boldsymbol{t}_{\boldsymbol{r}_\mathrm{p}}$)), can annihilate an electron with $\boldsymbol{p}_{t_\mathrm{p}}$ (Figs. 5 and 6).

$$e + \bar{e} \rightarrow \gamma + \gamma. \tag{41}$$

On the other hand, another positively charged particles with $\boldsymbol{p}_{t_\mathrm{p}}$ such as *u*, *c*, and *t* quarks do not annihilate a particle with $\boldsymbol{p}_{t_\mathrm{p}}$ such as an electron (Figs. 7 and 8).

$$e + u \rightarrow e + u. \tag{42}$$

This is the difference between the positrons with $\boldsymbol{p}_{t_\mathrm{a}}$ and another positively charged particles with $\boldsymbol{p}_{t_\mathrm{p}}$ such as *u*, *c*, and *t* quarks. We must elucidate the origin of the difference between them.

3.1 Electron–Positron Pair Annihilation

Let us consider the reason why an antiparticle with $\boldsymbol{p}_{t_\mathrm{a}}$ such as a positron can annihilate a particle with $\boldsymbol{p}_{t_\mathrm{p}}$ such as an electron (Figs. 5 and 6). When a low energy electron with $\boldsymbol{p}_{t_\mathrm{p}}$ annihilates a low-energy positron (antielectron) with $\boldsymbol{p}_{t_\mathrm{a}}$, they can only produce two gamma ray photons, since the electron with $\boldsymbol{p}_{t_\mathrm{p}}$ and positron with $\boldsymbol{p}_{t_\mathrm{a}}$ do not carry enough mass-energy to produce heavier particles, and conservation of energy and linear momentum forbid the creation of only one photon.

When an electron with $\boldsymbol{p}_{t_\mathrm{p}}$ and a positron with $\boldsymbol{p}_{t_\mathrm{a}}$ collide to annihilate and create gamma rays, energy is given off. Both particles with $\boldsymbol{p}_{t_\mathrm{p}}$ and antiparticles with $\boldsymbol{p}_{t_\mathrm{a}}$ have a rest energy of 0.511 mega electron volts (MeV). When the masses $q_{\mathrm{g},0}$ of the particles and antiparticles are converted entirely into energy, this rest energy is what is given off. The energy is given off in the form of the aforementioned gamma rays. Each of the gamma rays has an energy of 0.511 MeV. Since the positron with $\boldsymbol{p}_{t_\mathrm{a}}$ and electron with $\boldsymbol{p}_{t_\mathrm{p}}$ are both briefly at rest during this annihilation, the system has no momentum during that moment ($\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}} = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}} = 0$, $\boldsymbol{p}_{t_\mathrm{p}} + \boldsymbol{p}_{t_\mathrm{a}} = 0$). This is the reason why not one but two gamma rays are created.

The original saddle point ($\boldsymbol{p}_{\boldsymbol{r}_\mathrm{p}} = \boldsymbol{p}_{\boldsymbol{r}_\mathrm{a}} = 0$, $\boldsymbol{p}_{t_\mathrm{p}} + \boldsymbol{p}_{t_\mathrm{a}} = 0$) in the momentum-energy curve at the spacetime axis is the point where particle and antiparticle pair formation and annihilation occur. Let us consider the electron ($\boldsymbol{p}_{t_\mathrm{p}}$)–positron ($\boldsymbol{p}_{t_\mathrm{a}}$) pairs annihilation, as an example. By defining the center of mass as an original point, let us consider an electron with the position $+\boldsymbol{r}_{r_\mathrm{p}}$, the momentum $+\boldsymbol{p}_{r_\mathrm{p}}$, and the time momentum $+\boldsymbol{p}_{t_\mathrm{p}}$, and a positron with the position $+\boldsymbol{r}_{r_\mathrm{a}}$ $(=-\boldsymbol{r}_{r_\mathrm{p}})$, the momentum $+\boldsymbol{p}_{r_\mathrm{a}}$ $(=-\boldsymbol{p}_{r_\mathrm{p}})$, and the time momentum $+\boldsymbol{p}_{t_\mathrm{a}}$ $(=-\boldsymbol{p}_{t_\mathrm{p}})$ (Fig. 5).

Before an electron with $\boldsymbol{p}_{t_\mathrm{p}}$ and a positron with $\boldsymbol{p}_{t_\mathrm{a}}$ collide, the $\boldsymbol{p}_{r_\mathrm{p}}$ value as well as the $\boldsymbol{p}_{t_\mathrm{p}}$ value ($\boldsymbol{p}_{r_\mathrm{a}}$ value

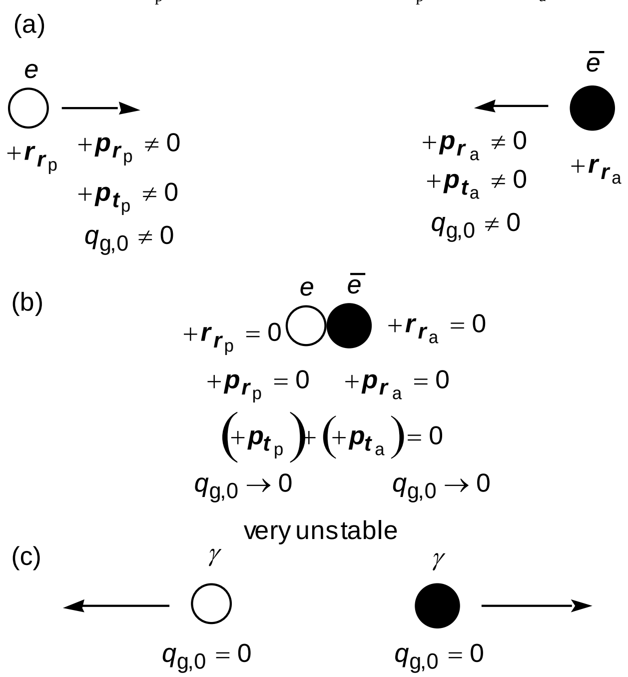

Fig. 5. Electron–positron annihilation. (a) Before annihilation. (b) During annihilation. (c) After annihilation.

as well as the $\boldsymbol{p}_{t_\mathrm{a}}$ value) are not 0, as expected (Figs. 5 (a) and 6 (a)),

$$p_{t,0}^2 = p_x^2 + p_y^2 + p_z^2 + p_t^2 \neq 0, \tag{43}$$

that is, the rest masses $q_{\mathrm{g},0}$ both for an electron and a positron are not zero,

$$(iq_{\mathrm{g},0}c)^2 = (q_\mathrm{g} v_x)^2 + (q_\mathrm{g} v_y)^2 + (q_\mathrm{g} v_z)^2 + (iq_\mathrm{g} c)^2 \neq 0, \tag{44}$$

$$q_{\mathrm{g},0} \neq 0. \tag{45}$$

On the other hand, when an electron and a positron collide to annihilate, gamma rays can be created (Figs. 5 (b), (c) and 6 (b), (d)). This can be understood as follows. When a negatively charged electron with $+\boldsymbol{p}_{t_\mathrm{p}}$ and a positively charged positron with $+\boldsymbol{p}_{t_\mathrm{a}}$ at the particle time axis ($\boldsymbol{t}_{t_\mathrm{p}}$) come closely to each other, they can finally contact by each other, because of the attractive electric forces. When an electron with $+\boldsymbol{p}_{t_\mathrm{p}}$ and a positron with $+\boldsymbol{p}_{t_\mathrm{a}}$ contact with each other at the original saddle point ($\boldsymbol{p}_{r_\mathrm{p}} = \boldsymbol{p}_{r_\mathrm{a}} = 0$, $\boldsymbol{p}_{t_\mathrm{p}} + \boldsymbol{p}_{t_\mathrm{a}} = 0$) at the spacetime axis,

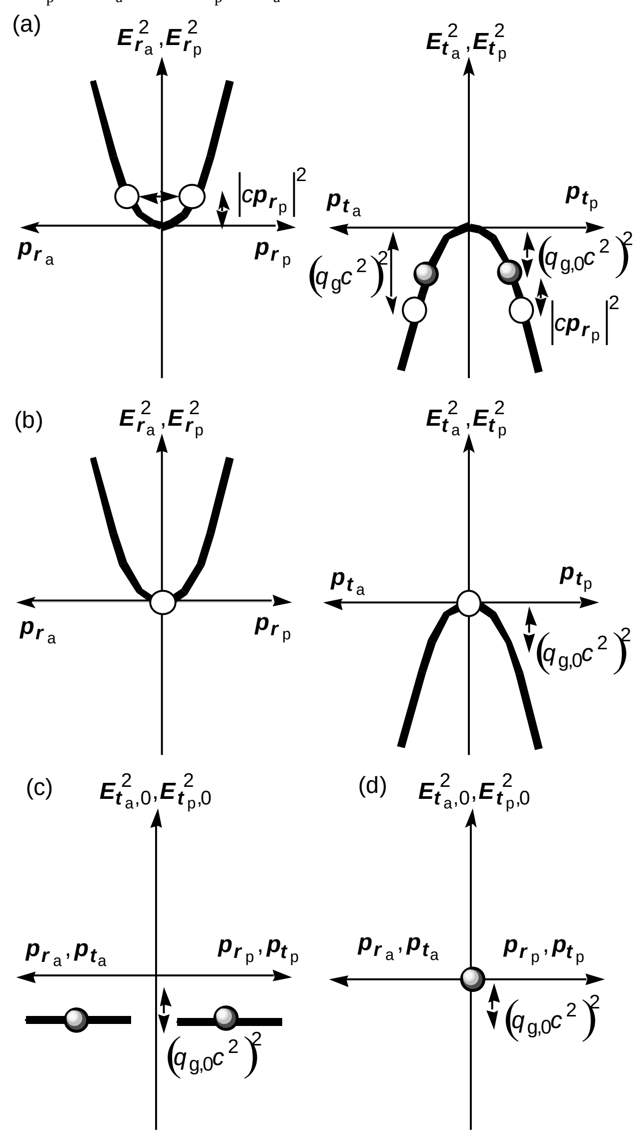

Fig. 6. Energies for electron–positron annihilation. (a) Energies for the space and time axes before annihilation. (b) Energies for the space and time axes during annihilation. (c) Total energies for the spacetime axis before annihilation. (d) Total energies for the spacetime axis during annihilation. In (a)–(d), the opened circles denote the energies for the space and time axes. The

shaded circles indicate the total energy for the spacetime axis.

physical values at the original saddle point becomes as follows (Figs. 5 (b) and 6 (b)),

$$\left(+\boldsymbol{r}_{r_{\mathrm{p}}}\right)=\left(+\boldsymbol{r}_{r_{\mathrm{a}}}\left(=\left(-\boldsymbol{r}_{r_{\mathrm{p}}}\right)\right)\right)=0, \quad (46)$$

$$\left(+\boldsymbol{p}_{r_{\mathrm{p}}}\right)=\left(+\boldsymbol{p}_{r_{\mathrm{a}}}\left(=\left(-\boldsymbol{p}_{r_{\mathrm{p}}}\right)\right)\right)=0, \quad (47)$$

$$\left(+\boldsymbol{p}_{t_{\mathrm{p}}}\right)+\left(+\boldsymbol{p}_{t_{\mathrm{a}}}\right)=\left(+\boldsymbol{p}_{t_{\mathrm{p}}}\right)+\left(-\boldsymbol{p}_{t_{\mathrm{p}}}\right)=0. \quad (48)$$

Therefore, at the original saddle point ($\boldsymbol{p}_{r_{\mathrm{p}}}=\boldsymbol{p}_{r_{\mathrm{a}}}=0$, $\boldsymbol{p}_{t_{\mathrm{p}}}+\boldsymbol{p}_{t_{\mathrm{a}}}=0$) at the spacetime axis, the total time momentum, which can be related to the time traveling velocity, becomes 0, as shown in Eq. (48). That is, the time is observed to be stopped by contacted electron and positron. In such a case, the time would not travel to any direction. The time traveling velocity for the massless particles ($\Delta\boldsymbol{t}_{t_{\mathrm{p}}}$) and antiparticles ($\Delta\boldsymbol{t}_{t_{\mathrm{a}}}$) would be 0.

$$\Delta\boldsymbol{t}_{t_{\mathrm{p}}}+\Delta\boldsymbol{t}_{t_{\mathrm{a}}}=0, \quad (49)$$

$$\boldsymbol{p}_{t_{\mathrm{p}}}+\boldsymbol{p}_{t_{\mathrm{a}}}=0. \quad (50)$$

According to the special relativity, for massless particles and antiparticles with $q_{\mathrm{g}}=0$ such as massless light, the scales of the space axis ($\Delta\boldsymbol{r}_{r_{\mathrm{p}}}$ and $\Delta\boldsymbol{r}_{r_{\mathrm{a}}}$) and the time traveling velocity ($\Delta\boldsymbol{t}_{t_{\mathrm{p}}}$ and $\Delta\boldsymbol{t}_{t_{\mathrm{a}}}$) are 0.

Therefore, when an electron with $\boldsymbol{p}_{t_{\mathrm{p}}}$ and a positron with $\boldsymbol{p}_{t_{\mathrm{a}}}$ collide, and behaves as one particle which stops for a very short time, the p_x, p_y, and p_z values as well as the p_t value, become 0 (Fig. 5 (b)). Therefore, the $q_{\mathrm{g},0}$ values ($\boldsymbol{p}_{t_{\mathrm{p}}}+\boldsymbol{p}_{t_{\mathrm{a}}}=0$) for an electron and a positron become 0.

$$\lim_{p_x,p_y,p_z,p_t\to 0}\left(p_{t,0}\right)^2 = \lim_{p_x,p_y,p_z,p_t\to 0}\left\{p_x^2+p_y^2+p_z^2+p_t^2\right\}=0, \quad (51)$$

that is, the rest masses $q_{\mathrm{g},0}$ both for an electron and a positron must become zero (Figs. 5 (b) and 6 (b), (d)),

$$\lim_{p_x,p_y,p_z,p_t\to 0}\left(iq_{\mathrm{g},0}c\right)^2 = \lim_{p_x,p_y,p_z,p_t\to 0}\left\{\left(q_{\mathrm{g}}v_x\right)^2+\left(q_{\mathrm{g}}v_y\right)^2+\left(q_{\mathrm{g}}v_z\right)^2+\left(iq_{\mathrm{g}}c\right)^2\right\}=0, \quad (52)$$

$$q_{\mathrm{g},0}=0. \quad (53)$$

This is the reason why the massless gamma rays can be created when massive electron and positron collide (Fig. 5 (c)).

We can also consider as follows. When an electron with $\boldsymbol{p}_{t_{\mathrm{p}}}$ and a positron with $\boldsymbol{p}_{t_{\mathrm{a}}}$ contact with each other, total time momentum vector becomes 0, as follows (Fig. 5 (b)),

$$\boldsymbol{p}_{t,\mathrm{total}}=\boldsymbol{p}_{t_{\mathrm{p}}}+\boldsymbol{p}_{t_{\mathrm{a}}}=0. \quad (54)$$

In such a case, since the p_t value becomes 0, the light-hand side of Eq. (9) becomes positive or zero,

$$p_x^2+p_y^2+p_z^2+p_t^2=p_x^2+p_y^2+p_z^2\geq 0, \quad (55)$$

on the other hand, the right-hand side of Eq. (9) should be always negative or zero,

$$p_{t,0}^2\leq 0. \quad (56)$$

Since the $p_x^2+p_y^2+p_z^2(\geq 0)$ value should be equal to the $p_{t,0}^2(\leq 0)$ value, we obtain

$$p_x^2+p_y^2+p_z^2=p_{t,0}^2=0. \quad (57)$$

This means that the imaginary rest momentum vector $p_{t,0}\left(=iq_{\mathrm{g},0}c\right)$ at the real space axis should be 0, and thus the rest mass $q_{\mathrm{g},0}$ must be 0 (Figs. 6 (b), (d)),

$$\left(q_{\mathrm{g}}v_x\right)^2+\left(q_{\mathrm{g}}v_y\right)^2+\left(q_{\mathrm{g}}v_z\right)^2=\left(iq_{\mathrm{g},0}c\right)^2=0, \quad (58)$$

$$q_{\mathrm{g},0}=0. \quad (59)$$

This is the reason why the massless gamma rays with $q_{\mathrm{g},0}=0$ can be created when massive electron with $q_{\mathrm{g},0}\neq 0$ and positron with $q_{\mathrm{g},0}\neq 0$ collide (Fig. 5 (c)). That is, the zero value of the total imaginary vector $\boldsymbol{p}_{t,\mathrm{total}}$ at the space axis as a consequence of the contact

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between a particle with the positive time traveling velocity $+\Delta \boldsymbol{t}_{t_\text{p}}$ and the positive imaginary momentum vector $+\boldsymbol{p}_{t_\text{p}}$ at the particle time axis, and an antiparticle with the negative time traveling velocity $+\Delta \boldsymbol{t}_{t_\text{a}}\left(=-\Delta \boldsymbol{t}_{t_\text{p}}\right)$ and the negative imaginary momentum vector $+\boldsymbol{p}_{t_\text{a}}\left(=-\boldsymbol{p}_{t_\text{p}}\right)$ at the particle time axis, is the reason why the spacetime becomes very unstable in energy (Figs. 5 (b) and 6 (b), (d)). In summary, destabilization of the spacetime in energy because of the zero value of the total imaginary time momentum ($\boldsymbol{p}_{t,\text{total}}$) and the zero value of the rest mass ($q_{\text{g},0}$) as a consequence of the contact between particles and antiparticles, is the reason why an antiparticle with $\boldsymbol{p}_{t_\text{a}}$ such as a positron can annihilate a particle with $\boldsymbol{p}_{t_\text{p}}$ such as an electron.

3.2 Electron–Up-Quark Interaction

Let us next consider the reason why a negatively charged particle with $\boldsymbol{p}_{t_\text{p}}$ such as an electron cannot annihilate a positively charged particle with $\boldsymbol{p}_{t_\text{p}}$ such as a u quark (Figs. 7 and 8).

Let us consider the interaction between two particles, for example, between a negatively charged electron with $\boldsymbol{p}_{t_\text{p}}$ and a positively charged u quark with $\boldsymbol{p}_{t_\text{p}}$. Let us consider an electron with the position $+\boldsymbol{r}_{r_\text{p}1}$, the momentum $+\boldsymbol{p}_{r_\text{p}1}$, and the time momentum $+\boldsymbol{p}_{t_\text{p}1}$, and a u quark with the position $+\boldsymbol{r}_{r_\text{p}2}$, the momentum $+\boldsymbol{p}_{\text{p}2}$, and the time momentum $+\boldsymbol{p}_{t_\text{p}2}$ (Fig. 7).

Before an electron with $\boldsymbol{p}_{t_\text{p}}$ and a u quark with $\boldsymbol{p}_{t_\text{p}}$ collide, the $\boldsymbol{p}_{r_\text{p}}$ value as well as the $\boldsymbol{p}_{t_\text{p}}$ value are not 0, as expected,

$$p_{t,0}^2 = p_x^2 + p_y^2 + p_z^2 + p_t^2 \neq 0, \tag{60}$$

that is, the rest masses $q_{\text{g},0}$ both for an electron and a u quark are not zero (Figs. 7 (a) and 8 (a)),

$$\left(iq_{\text{g},0}c\right)^2 = \left(q_\text{g} v_x\right)^2 + \left(q_\text{g} v_y\right)^2 + \left(q_\text{g} v_z\right)^2 + \left(iq_\text{g} c\right)^2 \neq 0, \tag{61}$$

$$q_{\text{g},0} \neq 0. \tag{62}$$

Even when an electron and a u quark collide, gamma rays cannot be created (Figs. 7 (b), (c) and 8 (b)-(d)). This can be understood as follows. When a negatively charged electron with $+\boldsymbol{p}_{t_\text{p}}$ and a positively charged u quark with $+\boldsymbol{p}_{t_\text{p}}$ at the particle time axis ($\boldsymbol{t}_{t_\text{p}}$) come closely to each other, they can finally contact by each other, because of the attractive electric forces. Even when an electron with $+\boldsymbol{p}_{t_\text{p}}$ and a u quark with $+\boldsymbol{p}_{t_\text{p}}$ contact with each other ($\boldsymbol{p}_{r_\text{p}1} = \boldsymbol{p}_{r_\text{p}2} = 0$), the total time momentum cannot become 0 ($\boldsymbol{p}_{t_\text{p}1} + \boldsymbol{p}_{t_\text{p}2} \neq 0$) (Figs. 7 (b) and 8 (b)),

$$\left(+\boldsymbol{r}_{r_\text{p}1}\right) = \left(+\boldsymbol{r}_{r_\text{p}2}\left(\approx\left(-\boldsymbol{r}_{r_\text{p}1}\right)\right)\right) = 0, \tag{63}$$

$$\left(+\boldsymbol{p}_{r_\text{p}1}\right) = \left(+\boldsymbol{p}_{r_\text{p}2}\left(\approx\left(-\boldsymbol{p}_{r_\text{p}1}\right)\right)\right) = 0, \tag{64}$$

$$\left(+\boldsymbol{p}_{t_\text{p}1}\right) + \left(+\boldsymbol{p}_{t_\text{p}2}\right) \approx 2\left(+\boldsymbol{p}_{t_\text{p}1}\right) \approx 2\left(+\boldsymbol{p}_{t_\text{p}2}\right) \neq 0. \tag{65}$$

Therefore, even at the contact point ($\boldsymbol{p}_{r_\text{p}1} = \boldsymbol{p}_{r_\text{p}2} = 0$) at the spacetime axis, the total time momentum, which can be related to the time traveling velocity, does not become 0. That is, the time is not observed to be stopped by contacted electron and u quark. The time traveling velocity for the massive particles ($\Delta \boldsymbol{t}_{t_\text{p}1}$ and $\Delta \boldsymbol{t}_{t_\text{p}2}$) would not be 0,

$$\Delta \boldsymbol{t}_{t_\text{p}1} \neq 0, \tag{66}$$

$$\Delta \boldsymbol{t}_{t_\text{p}2} \neq 0, \tag{67}$$

$$\boldsymbol{p}_{t_\text{p}1} \neq 0, \tag{68}$$

$$\boldsymbol{p}_{t_\text{p}2} \neq 0. \tag{69}$$

According to the special relativity, for massive particles with $q_\text{g} \neq 0$, the scales of the space axis ($\Delta \boldsymbol{r}_{r_\text{p}1}$ and $\Delta \boldsymbol{r}_{r_\text{p}2}$) and the time traveling velocity ($\Delta \boldsymbol{t}_{t_\text{p}1}$ and $\Delta \boldsymbol{t}_{t_\text{p}2}$) are not 0.

Therefore, even when an electron with $\boldsymbol{p}_{t_\text{p}1}$ and a u quark with $\boldsymbol{p}_{t_\text{p}2}$ collide, and behave as one particle which stops for a very short time, the p_t value does not become 0 (Figs. 7 (b) and 8 (b)),

$$\lim_{p_x, p_y, p_z \to 0} p_{t,0}^2 = \lim_{p_x, p_y, p_z \to 0} \left(p_x^2 + p_y^2 + p_z^2 + p_t^2\right)$$

$$= p_t^2 \neq 0, \qquad (70)$$

that is, the rest mass $q_{g,0}$ both for an electron and a u quark cannot become zero,

$$\lim_{p_x, p_y, p_z \to 0} (iq_{g,0}c)^2$$
$$= \lim_{p_x, p_y, p_z \to 0} \left\{ (q_g v_x)^2 + (q_g v_y)^2 + (q_g v_z)^2 + (iq_g c)^2 \right\}$$

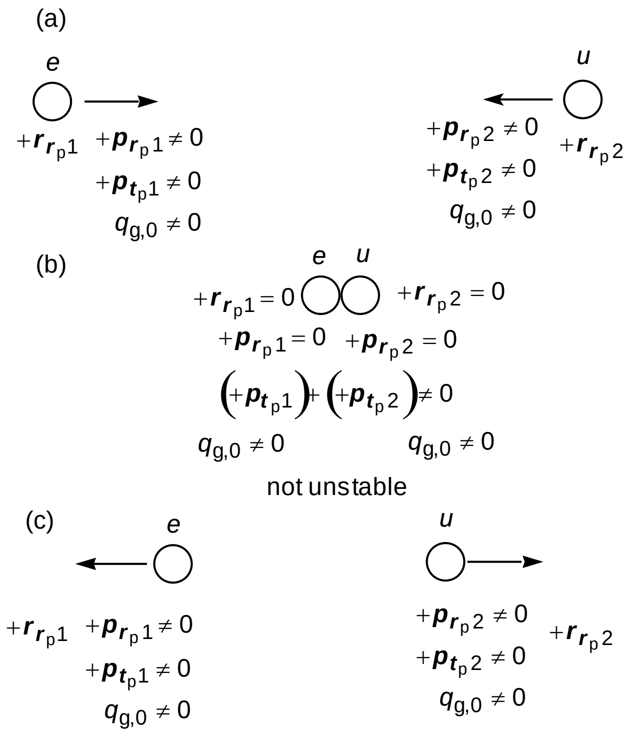

Fig. 7. Electron–up-quark collision. (a) Before collision. (b) During collision. (c) After collision.

$$= (iq_g c)^2 \neq 0, \qquad (71)$$

$$q_{g,0} \neq 0. \qquad (72)$$

This is the reason why the massless gamma rays cannot be created even when massive electron and u quark collide (Fig. 7 (c)).

We can also consider as follows. When an electron with $\boldsymbol{p}_{t_p 1}$ and a u quark with $\boldsymbol{p}_{t_p 2}$ contact with each other, total momentum vector does not become 0 (Figs. 7 (b) and 8 (b)), as follows,

$$\boldsymbol{p}_{t,\mathrm{total}} = \boldsymbol{p}_{t_p 1} + \boldsymbol{p}_{t_p 2} \approx 2\boldsymbol{p}_{t_p 1} \approx 2\boldsymbol{p}_{t_p 2} \neq 0. \qquad (73)$$

In such a case, since the p_t value becomes large negative, the right-hand side of Eq. (9) becomes always negative, as usual,

$$p_x^2 + p_y^2 + p_z^2 + p_t^2 \leq 0, \qquad (74)$$

on the other hand, the right-hand side of Eq. (9) should be always negative or zero,

$$p_{t,0}^2 \leq 0. \qquad (75)$$

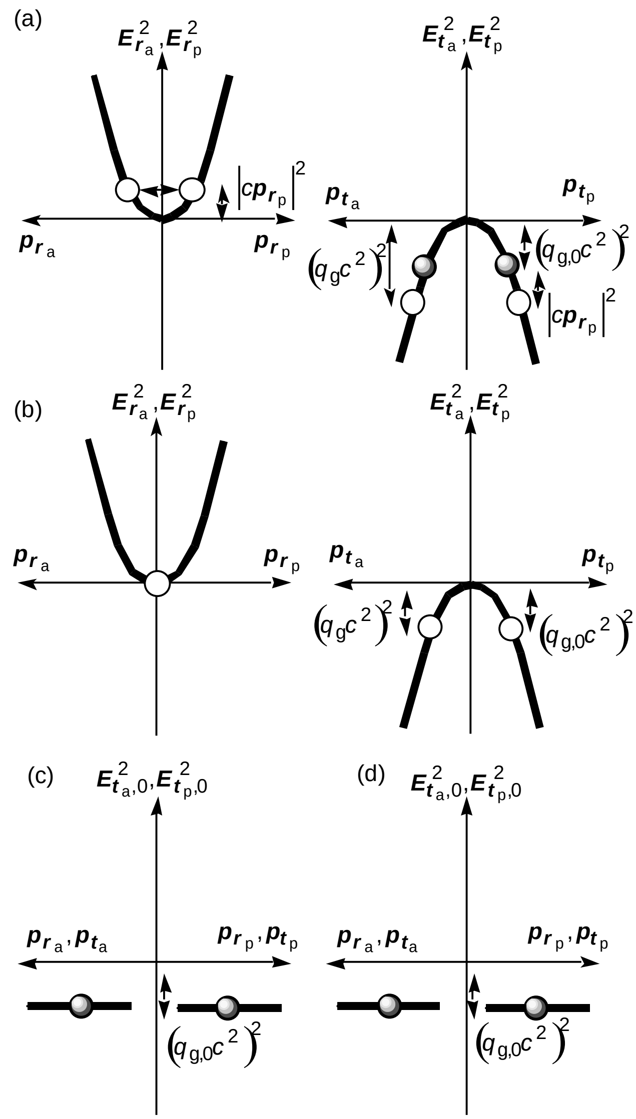

Fig. 8. Energies for electron–up-quark collision. (a) Energies for the space and time axes before collision. (b) Energies for the space and time axes during collision. (c) Total energies for the spacetime axis before collision. (d) Total energies for the spacetime axis during collision. In (a)–(d), the opened circles denote the energies for the

space and time axes. The shaded circles indicate the total energy for the spacetime axis.

This means that imaginary rest momentum vector $p_{t,0}\left(= iq_{g,0}c\right)$ at the real space axis should not be 0, and the rest mass $q_{g,0}$ should not be 0, as usual (Figs. 7 (b), (c) and 8 (b)-(d)),

$$\left(q_g v_x\right)^2 + \left(q_g v_y\right)^2 + \left(q_g v_z\right)^2 + \left(iq_g c\right)^2 = \left(iq_{g,0} c\right)^2 < 0, \quad (76)$$

$$q_{g,0} \neq 0. \quad (77)$$

This is the reason why the massless gamma rays with $q_{g,0} = 0$ cannot be created even when massive electron with $q_{g,0} \neq 0$ and u quark with $q_{g,0} \neq 0$ collide. That is, the finite value of the total imaginary vector $\boldsymbol{p}_{\boldsymbol{t},\mathrm{total}}$ at the space axis as a consequence of the contact between two particles with the positive time traveling velocity ($+\Delta \boldsymbol{t}_{\boldsymbol{t}_\mathrm{p}1}$ and $+\Delta \boldsymbol{t}_{\boldsymbol{t}_\mathrm{p}2}$) and the positive imaginary momentum vector ($+\boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}1}$ and $+\boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}2}$), is the reason why the spacetime does not become unstable in energy (Fig. 8 (b)). In summary, stable spacetime in energy because of the finite value of the total imaginary time momentum ($\boldsymbol{p}_{\boldsymbol{t},\mathrm{total}}$) as a consequence of the even contact between two particles is the reason why an particle with $\boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}}$ such as a u quark cannot annihilate a particle with $\boldsymbol{p}_{\boldsymbol{t}_\mathrm{p}}$ such as an electron (Figs. 7 (b), (c) and 8 (b)-(d)).

4. Concluding Remarks

In this research, we suggested the new interpretation of the spacetime axis in the special relativity. We also discussed the mechanism of the particle–antiparticle pair annihilation in view of the special relativity.

We suggest that the real world we live in is the complex 4-dimensional spacetime world which is formed by the real visible 3-dimensional space components (so-called, space axis) and by the imaginary invisible 1-dimensional space component (so-called, time axis), at the real 4-dimensional space axis.

The 4-dimensional spacetime axis can be interpreted by various definitions as follows. The components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and of the 1-dimensional real time vectors at the 1-dimensional real time axis. The components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and the 1-dimensional real time vectors at the 1-dimensional imaginary space axis. The components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and of the 1-dimensional imaginary time vectors at the 1-dimensional real space axis. In the discussion in this article, we used the definition that the components of the 4-dimensional spacetime axis are composed of the 3-dimensional real space vectors at the 3-dimensional real space axis and of the 1-dimensional imaginary time vectors at the 1-dimensional real space axis.

The momentum p_x, p_y, and p_z values are related to the real components at the real space axis, x, y, and z, respectively. The energy E_t is related to the real (imaginary) component at the real time (real space) axis. The p_t and $p_{t,0}$ (E_t / c and $E_{t,0} / c$) terms are usually considered to be related to the energy, that is, related to the real components at the time axis. On the other hand, if we consider that we live in the real visible momentum axis, which is related to the real space axis, the energy can be considered to be the imaginary invisible momentum component at the real space axis. Therefore, we can consider that the p_t and E_t terms, and the $p_{t,0}$ and $E_{t,0}$ terms, are related to the real time component (imaginary space component), on the other hand, the ip_t and iE_t terms, and the $ip_{t,0}$ and $iE_{t,0}$ terms are related to the real space component (imaginary time component).

We can consider that the original point ($p_x = p_y = p_z = p_t = 0$) at the spacetime axis in energy is saddle point (massless transition state (TS)) of the converting reaction between massive particle and antiparticle states in momentum-energy curves. The original point ($p_x = p_y = p_z = p_t = 0$) is the minimum point in energy at the p_x, p_y, and p_z axes ($p_x = p_y = p_z = 0$), on the other hand, that is the maximum point in energy at the real space axis at the p_t axis ($p_t = 0$). Therefore, the space can be considered to be real components (reversible) of the space axis at the spacetime axis. On the other hand, the time can be considered to be the imaginary components (irreversible) of the space axis at the spacetime axis. That is, the 3-dimensional space components are real components in the real 3-dimensional space axis, and the 1-dimensional time components are the imaginary components in the 1-dimensional real space axis.

The original point of the space axis at the spacetime axis is the bottom point, and the most stable in energy. Therefore, only small energy is needed for space to reverse at the real space axis. Therefore, the reversible process from the $+\boldsymbol{r}_{\boldsymbol{r}_\mathrm{p}}$ to the $-\boldsymbol{r}_{\boldsymbol{r}_\mathrm{p}}$ (from the $+\boldsymbol{r}_{\boldsymbol{r}_\mathrm{a}}$ to the

$-\boldsymbol{r}_{r_a}$) can be possible, and we can observe the real space axis, visibly. This is the reason why momentum vectors $\boldsymbol{p}_{r_p}$ and $\boldsymbol{p}_{r_a}$, and related space axis $\boldsymbol{r}_{r_p}$ and $\boldsymbol{r}_{r_a}$, are the 3-dimensional real vectors at the real space axis.

The time can be considered to be the imaginary components (irreversible) of the space axis at the spacetime axis. The original point of the time at the real space axis is the top point, and the most unstable in energy. Therefore, very large energy is needed for the time to reverse at the real space axis. Therefore, the reversible process from the future $+\boldsymbol{t}_{t_p}$ ($+i\boldsymbol{t}_{r_p}$) to the past $-\boldsymbol{t}_{t_p}$ ($-i\boldsymbol{t}_{r_p}$) (from the future $+\boldsymbol{t}_{t_a}$ ($+i\boldsymbol{t}_{r_a}$) to the past $-\boldsymbol{t}_{t_a}$ ($-i\boldsymbol{t}_{r_a}$)) cannot be possible, furthermore, we cannot observe the real time (imaginary components) at the real space axis, visibly. This is the reason why the energy $\boldsymbol{E}_{t_p}$ ($= i\boldsymbol{E}_{r_p}$) and $\boldsymbol{E}_{t_a}$ ($= i\boldsymbol{E}_{r_a}$), and related time axis $\boldsymbol{t}_{t_p}$ ($= i\boldsymbol{t}_{r_p}$) and $\boldsymbol{t}_{t_a}$ ($= i\boldsymbol{t}_{r_a}$), are considered to be not vector but scalar. On the other hand, we can interpret that the energy vectors $\boldsymbol{E}_{t_p}$ ($= i\boldsymbol{E}_{r_p}$) and $\boldsymbol{E}_{t_a}$ ($= i\boldsymbol{E}_{r_a}$), and related time axis $\boldsymbol{t}_{t_p}$ ($= i\boldsymbol{t}_{r_p}$) and $\boldsymbol{t}_{t_a}$ ($= i\boldsymbol{t}_{r_a}$), are the 1-dimensional imaginary vectors at the real space axis.

According to this research, the space axis is the real 3-dimensional space vector in the spacetime axis. Momentum is the real 3-dimensional momentum vector at the real space axis in the spacetime axis. The time is the imaginary 1-dimensional space vector at the real space axis in the spacetime axis. The energy is the imaginary 1-dimensional momentum vector at real space axis in the spacetime axis.

The total spacetime energy ($\left|\boldsymbol{E}_{t_p,0}\right|$) originating from the space axis ($\left|\boldsymbol{E}_{r_p}\right|$) and the time axis ($\left|\boldsymbol{E}_{t_p,0}\right|$) try to become always constant by distortion of the spacetime. At the same time, the scale of the space $\Delta\boldsymbol{r}_{r_p}$ and the time traveling velocity $\Delta\boldsymbol{t}_{t_p}$ decreases with an increase in the $\boldsymbol{p}_{r_p}$ value. Spacetime becomes very unstable in energy if the $\boldsymbol{p}_{t_p}$ value becomes 0. That is, the time traveling velocity $\Delta\boldsymbol{t}_{t_p}$ and imaginary time momentum vector $\boldsymbol{p}_{t_p}$ at the real space axis (momentum at the time axis), related to the rest mass $q_{g,0}$, play an essential role in the forming of the stable real spacetime world we live in.

The time traveling velocity can be decided by the rest mass $q_{g,0}$ of particle or antiparticle at $p_x = p_y = p_z = 0$. The rest mass $q_{g,0}$ of particle and antiparticle plays an essential role in the forming of the stable spacetime world for particles and antiparticles, respectively. The stabilization energy for the spacetime increases with an increase in the rest mass $q_{g,0}$.

We discussed the reason why an antiparticle with $\boldsymbol{p}_{t_a}$ such as a positron can annihilate a particle with $\boldsymbol{p}_{t_p}$ such as an electron. When an electron and a positron collide to annihilate, gamma rays can be created. This can be understood as follows. When a negatively charged electron with $+\boldsymbol{p}_{t_p}$ and a positively charged positron with $+\boldsymbol{p}_{t_a}$ at the particle time axis ($\boldsymbol{t}_{t_p}$) come closely to each other, they can finally contact by each other, because of the attractive electric forces. When an electron with $+\boldsymbol{p}_{t_p}$ and a positron with $+\boldsymbol{p}_{t_a}$ contact with each other at the original saddle point ($\boldsymbol{p}_{r_p} = \boldsymbol{p}_{r_a} = 0$, $\boldsymbol{p}_{t_p} + \boldsymbol{p}_{t_a} = 0$) at the spacetime axis, the total time momentum, which can be related to the time traveling velocity, becomes 0. Therefore, when an electron with $\boldsymbol{p}_{t_p}$ and a positron with $\boldsymbol{p}_{t_a}$ collide, and behaves as one particle which stops for a very short time, the p_x, p_y, and p_z values as well as the p_t value, become 0. Therefore, the $q_{g,0}$ values ($\boldsymbol{p}_{t_p} + \boldsymbol{p}_{t_a} = 0$) for an electron and a positron become 0. This is the reason why the massless gamma rays with $q_{g,0} = 0$ can be created when massive electron with $q_{g,0} \neq 0$ and positron with $q_{g,0} \neq 0$ collide. That is, the zero value of the total imaginary vector $\boldsymbol{p}_{t,\text{total}}$ at the space axis as a consequence of the contact between a particle with the positive time traveling velocity $+\Delta\boldsymbol{t}_{t_p}$ and the positive imaginary momentum vector $+\boldsymbol{p}_{t_p}$ at the particle time axis, and an antiparticle with the negative time traveling velocity $+\Delta\boldsymbol{t}_{t_a}\left(= -\Delta\boldsymbol{t}_{t_p}\right)$ and the negative imaginary momentum vector $+\boldsymbol{p}_{t_a}\left(= -\boldsymbol{p}_{t_p}\right)$ at the particle time axis, is the reason why the spacetime becomes very unstable in energy. In summary, destabilization of the spacetime in energy because of the zero value of the total imaginary time momentum ($\boldsymbol{p}_{t,\text{total}}$) and the zero value of the rest mass ($q_{g,0}$) as a consequence of the contact between particles and antiparticles, is the reason why an antiparticle with $\boldsymbol{p}_{t_a}$ such as a positron can annihilate a particle with $\boldsymbol{p}_{t_p}$ such as an electron.

We also discussed the reason why a negatively charged particle with $\boldsymbol{p}_{t_p}$ such as an electron cannot annihilate a positively charged particles with $\boldsymbol{p}_{t_p}$ such as a u quark. Even when a negatively charged electron with $+\boldsymbol{p}_{t_p}$ and a positively charged u quark with $+\boldsymbol{p}_{t_p}$ at the particle time axis ($\boldsymbol{t}_{t_{\mathrm{p}}}$) come closely to each other, they can finally contact by each other, because of the attractive electric forces. That is, even when an electron with $+\boldsymbol{p}_{t_{\mathrm{p}}}$ and a u quark with $+\boldsymbol{p}_{t_{\mathrm{p}}}$ contact with each other ($\boldsymbol{p}_{r_{\mathrm{p}}1} = \boldsymbol{p}_{r_{\mathrm{p}}2} = 0$), the total time momentum cannot become 0 ($\boldsymbol{p}_{t_{\mathrm{p}}1} + \boldsymbol{p}_{t_{\mathrm{p}}2} \neq 0$). In other words, even at the contact point ($\boldsymbol{p}_{r_{\mathrm{p}}1} = \boldsymbol{p}_{r_{\mathrm{p}}2} = 0$) at the spacetime axis, the total time momentum, which can be related to the time traveling velocity, does not become 0. That is, the time is not observed to be stopped by contacted electron and u quark. The time traveling velocity for the massive particles ($\Delta\boldsymbol{t}_{t_{\mathrm{p}}1}$ and $\Delta\boldsymbol{t}_{t_{\mathrm{p}}2}$) would not be 0. This is the reason why the massless gamma rays with $q_{\mathrm{g},0} = 0$ cannot be created even when massive electron with $q_{\mathrm{g},0} \neq 0$ and u quark with $q_{\mathrm{g},0} \neq 0$ collide. That is, the finite value of the total imaginary vector $\boldsymbol{p}_{t,\mathrm{total}}$ at the space axis as a consequence of the contact between two particles with the positive time traveling velocity ($+\Delta\boldsymbol{t}_{t_{\mathrm{p}}1}$ and $+\Delta\boldsymbol{t}_{t_{\mathrm{p}}2}$) and the positive imaginary momentum vector ($+\boldsymbol{p}_{t_{\mathrm{p}}1}$ and $+\boldsymbol{p}_{t_{\mathrm{p}}2}$), is the reason why the spacetime does not become unstable in energy. In summary, stable spacetime in energy because of the finite value of the total imaginary time momentum ($\boldsymbol{p}_{t,\mathrm{total}}$) as a consequence of the even contact between two particles, is the reason why an particle with $\boldsymbol{p}_{t_{\mathrm{p}}}$ such as a u quark cannot annihilate a particle with $\boldsymbol{p}_{t_{\mathrm{p}}}$ such as an electron.

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