

Speculations on the Neutrino Theory of Light

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ABSTRACT. We first review the old attempts to construct the ‘neutrino theory of light’ and present the Berezinsky conditions, under which this theory can be uncontradictory. Then, we review recent developments in the quantum theory of particles with spin. The basis of new ideas in the old theory is the Majorana and Ahluwalia constructs, modified versions of the Weinberg $2(2j+1)$ theory, and the Barut’s self-field quantum electrodynamics. Furthermore, we ask several questions which are relevant to correct interpretation of the obtained results. Finally, on the basis of recent papers we discuss where the Berezinsky conditions may fail.

1 Answers

The neutrino theory of light has a long history [1]-[26]. Its crucial point was the Pryce theorem [8] which brought a halt in the development of this branch of particle physics for a long time. Namely, as showed Barbour *et al.* in the most elegant way, ref. [10], the Jordan’s “ansatz”¹

$$\mathcal{A}_\mu(k) = \int_0^1 f(\lambda) \bar{\psi}((\lambda-1)k) \gamma_\mu \psi(\lambda k) d\lambda \quad (1)$$

was thought to be incompatible with the requirement of the transversality of a photon and/or with the requirements of the correct statistics for a photon.

¹ $\mathcal{A}_\mu(k)$ is the electromagnetic potential in the momentum space. Here k is the photon four-momentum, γ_μ the usual 4×4 matrices and ψ is the spin-1/2 field operator. $f(\lambda)$ is some suitable weight function. In the de Broglie theory one has $f(\lambda) = \delta(\lambda - a)$.

In the sixties some hopes on recreation emerged, the renaissance occurred. Berezinsky writes [15]: “With a gauge transformation the amplitude of a photon state of the type:

$$m\bar{\psi}(\tau k)\gamma_{\mu}\psi(\lambda k) = -ik_{\mu}\bar{\psi}(\tau k)\psi(\lambda k) \quad (2)$$

(λ and τ are numbers) can always be reduced to zero” and then he disagrees with I. M. Barbour *at al.*: “In the four-component theory there is no difficulty in practically constructing all transverse four-vectors from the wave functions of neutrinos with collinear momenta”.

Sen, ref. [11], writes: “... the 2-component neutrino can also be completely described by a self-dual antisymmetric tensor behaving very much like the electromagnetic field tensor. What about the anti-self-dual case? ... We have shown that the photon can be considered as a combination of two neutrinos, one described by

$$(\sigma_k\partial_k + i\partial_4)\phi = 0 \quad (3)$$

and other by

$$(\sigma'_k\partial_k + i\partial_4)\chi = 0 \quad (4)$$

(the set σ'_k differs from σ_k only by the interchange of the indices one and three) and that the neutrinos described by (3) and (4) can be represented by a self-dual and an anti-self-dual antisymmetric tensor, respectively. The two neutrinos will behave identically when they are free but their interactions with other particles may be different. The problem of how they differ in their interactions remains to be investigated.”

Bandyopadhyay, ref. [19], continues: “Perkins, ref. [13], considered the usual four-component solutions with definite momentum and helicity of the Dirac equation with a zero-mass term. He constructed in some special way the electromagnetic field tensor $F_{\mu\nu}$ of the two neutrino operators in the configurational space. In this formalism, the photon appears as composed of the pair $(\nu_1\bar{\nu}_2)$ and $(\nu_2\bar{\nu}_1)$, where ν_1 (ν_2) denotes the neutrino with spin parallel (antiparallel) to its momentum. However, the impossibility of constructing linearly polarized photons seems to be a very serious defect of this theory. ... we can say that the construction of the photon as a composite state of a neutrino-antineutrino pair has remained a problem until now.”

Strazhev concludes [22]: “Neutrino and photon states realize the IR [irreducible representations] of chiral group $U(1)$ and all the relations

that connect the neutrino and photon operators must have definite transformation properties under chiral transformation. The electromagnetic potentials $\mathcal{A}_\mu(k)$ are not dual invariants. At the same time the right side of the expression (1) is an invariant of γ_5 transformations. Of course, from the particular solutions of the Dirac equation with mass $m = 0$ can be built the transversal four-vector (Berezinsky, 1966, ref. [15]) ... In this case, however, the condition of the relativistic invariance will not be satisfied. So, we can formulate the Pryce theorem in the following way: The requirements of the correct statistics and the correct transformation properties under transformation of the group $U(1)$ of the composite photons are incompatible in the neutrino theory of light. In other words we can say that with the satisfaction of the requirement of the relativistic and chiral invariance one can build from the neutrino only a photon with unphysical longitudinal polarization.” .

A succeeding halt! ...

2 Thoughts

I would still like to mention here: very unfortunately the paper of Sen [11] did not draw almost any attention. I believe that it was in the needed direction. Furthermore, it is not clear to me, why do peoples, speaking about the *neutrino* theory of light, used the Dirac field operator which describes *charged particles*? Finally, in the recent textbook on the quantum field theory [27] S. Weinberg indicated the possibility that the 4-vector potential can be used to describe a scalar particle ... So, it seems to me that some speculations about the problem, which is overweighed by many confusions, would be desirable.

In ref. [15] the following assumptions have been made, under which one can have the consistent neutrino theory of light.

“1. Let U_θ be an operator which in the space of neutrino state vectors describes a rotation by angle θ around the direction of the momentum \mathbf{k} as an axis. Then

$$U_\theta a_i(\mathbf{k}) U_\theta^{-1} = e^{i\theta/2} a_i(\mathbf{k}) \quad , \quad U_\theta b_i(\mathbf{k}) U_\theta^{-1} = e^{-i\theta/2} b_i(\mathbf{k}) \quad . \quad (5)$$

2. If the neutrinos are fermions, then the operators $a_i(\mathbf{k})$ and $b_i(\mathbf{k})$ obey the following commutation relations:

$$[a_i^+(\mathbf{k}), a_j(\mathbf{k}')]_+ = [b_i^+(\mathbf{k}), b_j(\mathbf{k}')]_+ = \delta_{ij} \delta(\mathbf{k} - \mathbf{k}') \quad . \quad (6)$$

*All other anticommutators are equal to zero.*²

3. *There exist photons with right and left circular polarization, whose annihilation operators $\kappa(\mathbf{p})$ and $\omega(\mathbf{p})$ have the following transformation properties:*

$$U_\theta \kappa(\mathbf{p}) U_\theta^{-1} = e^{i\theta} \kappa(\mathbf{p}) \quad , \quad U_\theta \omega(\mathbf{p}) U_\theta^{-1} = e^{-i\theta} \omega(\mathbf{p}) \quad . \quad (7)$$

4. *Simultaneously there exist photons with linear polarization, whose annihilation operators $\xi(\mathbf{p})$ and $\eta(\mathbf{p})$ are linear combinations of $\kappa(\mathbf{p})$ and $\omega(\mathbf{p})$ and satisfy the transformation relations*

$$U_\theta \xi(\mathbf{p}) U_\theta^{-1} = \xi(\mathbf{p}) \cos \theta + \eta(\mathbf{p}) \sin \theta \quad , \quad (8a)$$

$$U_\theta \eta(\mathbf{p}) U_\theta^{-1} = -\xi(\mathbf{p}) \sin \theta + \eta(\mathbf{p}) \cos \theta \quad . \quad (8b)$$

5. *It is also assumed that the photon operators satisfy the following commutation relations:*

$$[\xi(\mathbf{p}), \eta^+(\mathbf{p})]_- = 0, \quad [\kappa(\mathbf{p}), \omega^+(\mathbf{p})]_- = 0 \quad . \quad (9)$$

Equations (9) are the conditions for the photon to be genuinely neutral. No assumptions are made about the equations for the photons or the neutrinos."

Strazhev, ref. [22], reformulated them in a following way: "The operators of the massless fields have the definite transformation rules under chiral (γ_5) transformations; there exist field operators \vec{E} , \vec{H} that are transformed under dual transformations in accordance with

$$U_\theta \Phi_i U_\theta^{-1} = \Phi_i \cos \theta + \tilde{\Phi}_i \sin \theta \quad (10)$$

$$U_\theta \tilde{\Phi}_i U_\theta^{-1} = -\Phi_i \sin \theta + \tilde{\Phi}_i \cos \theta \quad , \quad (11)$$

(where $i = 1, 2$); a neutrino can be either a fermion or a parafermion particle; the commutation relations of the operators of the photon fields are invariants under dual transformations ... The last condition is an equivalent to the condition of the pure neutrality of the photon by Berezinsky ... We do not have a self-consistent neutrino theory of light if all these conditions are satisfied. From our point of view, that means that the

²We still note that another set of anticommutation relations has been recently proposed [28] in the Majorana-McLennan-Case-like construct.

statistical properties of the photon in the neutrino theory of light are inconsistent with the chiral (γ_5) symmetry of neutrino and electromagnetic fields.”

At this point I would like to remind recent results obtained in the framework of the $2(2j+1)$ component theory [29]-[31], the antisymmetric tensor field description [32, 33] and in the Majorana theory of neutral particles [34, 35].

- D. V. Ahluwalia and D. J. Ernst found that the Weinberg first-order equations for massless free particle of arbitrary spin

$$(\mathbf{J} \cdot \mathbf{p} - jp^0) \phi_R(\mathbf{p}) = 0 \quad , \quad (12a)$$

$$(\mathbf{J} \cdot \mathbf{p} + jp^0) \phi_L(\mathbf{p}) = 0 \quad (12b)$$

have acausal solutions. For instance, for the spin $j = 1$ case one has the puzzled solution $E = 0$, see Table 2 in ref. [36]. The satisfactory explanation is required to this solution not only from the physical viewpoint but from the methodological viewpoint too.³ On the other hand, the $m \rightarrow 0$ limit of the Weinberg equation [and the Dirac-like modification of the Weinberg equation [40]] of the $2j$ -order in derivatives is free from all kinematic acausalities.

- M. Moshinsky and A. del Sol Mesa, ref. [41], noted that for a two-equal-mass-particle system in relativistic quantum mechanics three possible dispersion relations (Eq. (1.5) of the cited work) exist:

$$E = E_1 + E_2 = \begin{cases} +(2\mathbf{p}^2c^2 + 4m^2c^4)^{1/2} \\ 0 \\ -(2\mathbf{p}^2c^2 + 4m^2c^4)^{1/2} \end{cases} \quad , \quad (13)$$

where $\mathbf{p}_1 = -\mathbf{p}_2 \equiv \frac{1}{\sqrt{2}}\mathbf{p}$. They called the infinitely degenerate level $E = 0$ as the “relativistic cockroach nest”, “as it appears inert so long as the particles are free, but any interaction immediately

³See also the discussion in refs. [37, 38]. The concept of ‘action-at-a-distance’ presented by A. E. Chubykalo and R. Smirnov-Rueda [39] may also be connected with the problem at hand. The situation is now similar to that which we encountered in the twenties. The explanation was required in that time for negative-energy solutions in the famous equation for spin $j = 1/2$. In the opposite case (if we would not find a satisfactory interpretation for the $E = 0$ solution) we have to agree with Weinberg [29b,p.B888]: “The fact that these field equations are of first order for any spin seems to me to be of no great significance...”

brings levels at values $E \neq 0$. The name [they] have given to these levels comes from its analogy with a crack in a wall, which looks innocuous under normal circumstances, but if food is put near it, *i.e.* in our case interaction, the cockroaches start to come out... Analogy indicates that food near the crack will keep the cockroaches there, and thus will not hamper our use of the rest of the wall.”

- In ref. [69] the concept of *magnetic (second) photon* was discussed extensively.⁴
- In ref. [40] an explicit construct of the Bargmann-Wightman-Wigner-type quantum field theory has been proposed in the $(1, 0) \oplus (0, 1)$ representation space of the Lorentz group. The remarkable feature of this class of theories, envisaged in the sixties [42], is: a boson and its antiboson can possess opposite relative intrinsic parities. The essential ingredients of this model are: the choice of the spinorial basis (or, rather, of bivectors in the zero-momentum frame) in the same manner like in the spin $j = 1/2$ case:⁵ $\phi_R(\overset{\circ}{p}^\mu) = \pm \phi_L(\overset{\circ}{p}^\mu)$; and the use of the Wigner rules [44] for Lorentz transformations of the right- $(j, 0)$ and left- $(0, j)$ handed spinors from the “rest”:

$$(j, 0) : \quad \phi_R(p^\mu) = \exp(+\mathbf{J} \cdot \boldsymbol{\varphi}) \phi_R(\overset{\circ}{p}^\mu) \quad , \quad (14a)$$

$$(0, j) : \quad \phi_L(p^\mu) = \exp(-\mathbf{J} \cdot \boldsymbol{\varphi}) \phi_L(\overset{\circ}{p}^\mu) \quad . \quad (14b)$$

As a result, the Weinberg $(1, 0) \oplus (0, 1)$ configuration-space-free-equation has been modified:⁶

$$(\gamma_{\mu\nu} \partial^\mu \partial^\nu + \wp_{u,v} m^2) \psi(x) = 0 \quad (15)$$

with $\wp_u = 1$ for positive-energy solutions and $\wp_v = -1$, for the negative-energy solutions.

Various problems of describing the particle world in the $(j, 0) \oplus (0, j)$ representation space have also been discussed in the works [37, 46, 47].

⁴15.07.99. Unfortunately, I become to be aware about these papers recently only. My latest preprints math-ph/9808005, math-ph/9805017, physics/9804010 develop, in fact, this concept.

⁵See also my recent works [43].

⁶Matrices $\gamma_{\mu\nu}$ are the Barut-Muzinich-Williams covariantly defined matrices [45] in the $(1, 0) \oplus (0, 1)$ representation space.

- In ref. [48] the equivalence of the Weinberg field, which satisfies the equations

$$(\gamma_{\alpha\beta}p_\alpha p_\beta + m^2)\psi_1(x) = 0 \quad , \quad (16a)$$

$$(\gamma_{\alpha\beta}p_\alpha p_\beta - m^2)\psi_2(x) = 0 \quad , \quad (16b)$$

and the antisymmetric tensor field, which satisfies the equations

$$m^2 F_{\mu\nu} = \partial_\mu \partial_\alpha F_{\alpha\nu} - \partial_\nu \partial_\alpha F_{\alpha\mu} + \frac{1}{2}(m^2 - \partial_\lambda^2)F_{\mu\nu} \quad , \quad (17a)$$

$$m^2 \tilde{F}_{\mu\nu} = \partial_\mu \partial_\alpha \tilde{F}_{\alpha\nu} - \partial_\nu \partial_\alpha \tilde{F}_{\alpha\mu} + \frac{1}{2}(m^2 - \partial_\lambda^2)\tilde{F}_{\mu\nu} \quad , \quad (17b)$$

has been proved. The concept of the Weinberg field as a system of two field function $(\psi_1(x), \psi_2(x))$ (or $(F_{\mu\nu}(x), \tilde{F}_{\mu\nu}(x))$) has been proposed. In ref. [50] the Weinberg propagators for the spin $j = 1$ field have been constructed on the basis of the use of this set of field functions and parity-conjugates to them.

Let me still note, the equations (16a)-(17b) have both solutions with a correct physical dispersion $E^2 - \vec{p}^2 = m^2$ and tachyonic solutions. The Hammer-Tucker equation, ref. [31], or the Proca equations for an antisymmetric tensor field:

$$m^2 F_{\mu\nu} = \partial_\mu \partial_\alpha F_{\alpha\nu} - \partial_\nu \partial_\alpha F_{\alpha\mu} \quad , \quad (18a)$$

$$\partial_\lambda^2 F_{\mu\nu} = m^2 F_{\mu\nu} \quad . \quad (18b)$$

(and dual to them) was mentioned in ref. [48] to possess six causal solutions for massive particles. Moreover, in the case $m = 0$ the determinant of the Hammer-Tucker equations is identically equal to zero.⁷ The corresponding Green's function for the general case (see the similar expression of the Green's function for massless field in [51]), written on using the Euclidean metric, is

$$G_{\mu\nu,\alpha\beta}(p) = -\frac{1}{c_1 p^2 + c_2 m^2} \left[(\delta_{\mu\alpha} \delta_{\nu\beta} - \delta_{\mu\beta} \delta_{\nu\alpha}) - \frac{1}{(c_1 + 1)p^2 + c_2 m^2} (p_\mu p_\alpha \delta_{\nu\beta} - p_\mu p_\beta \delta_{\nu\alpha} - p_\nu p_\alpha \delta_{\mu\beta} + p_\nu p_\beta \delta_{\mu\alpha}) \right] \quad (19)$$

⁷In this work we are not going to discuss advantages and shortcomings coming from the choice of Weinberg or Tucker-Hammer equations. These issues have been mentioned in previous works but still deserve a separate paper.

The constants $c_{1,2}$ are defined by the equation considered (see [48, Eq.(9)]). In the case of the Hammer-Tucker equation $c_1 = 0$ and the Green's function is not well-defined in the massless limit.

- In the papers, refs. [49, 52], the transversality (including a massless case) of the Weinberg (or antisymmetric tensor) fields has been proved. This statement opposes to the conclusions of refs. [32, 33, 51] and of my previous paper [47b]. In those papers it was claimed that the quantized massless antisymmetric tensor field is longitudinal. What are the origins of such a surprising result achieved in earlier articles? As a matter of fact it contradicts with the classical formalism for antisymmetric tensor field (*i.e.*, with the Correspondence Principle) and with the famous Weinberg theorem $B - A = \lambda$, which allows the helicity of the $(1,0) \oplus (0,1)$ massless field to be $\lambda = \pm 1$. In the old works several authors have applied the “generalized Lorentz condition” imposed on the state vectors (see formulas (18) in ref. [32]). It is the “generalized Lorentz condition”, which coincides with the equations (12a,12b), that yields the puzzled dispersion relation of the $j = 1$ massless field (*cf.* with item # 1). The papers [49, 52] reveal that the use of the well-known equations (12a,12b) in the coordinate space may lead to confusions such as equating the spin operator to zero. The result which is related with our conclusion has been confirmed by Evans [53] from different standpoints. He discussed origins of appearance of the $B(3)$ longitudinal field, which may be used to obtain helicities ± 1 . Unfortunately, formal calculations in Evans' papers deserve careful examination. In the paper [51] Avdeev and Chizhov analyzed this problem and used the Lagrangian which is similar to our Lagrangian except for the total derivative.⁸ But, they concerned with the real part of the antisymmetric tensor field only and lost the information about possible existence of the $j = 1$ antiparticle. Furthermore, in the private communications Prof. L. Avdeev writes himself: “In perturbation theory we systematically ignore any boundary effects, although they may be of consequence nonperturbatively.” Interesting discussion of the above-mentioned issues can be found in ref. [54].

⁸Our term, ref. [52, Eq. (3)], $\sim \partial_\mu F_{\nu\alpha} \partial_\nu F_{\mu\alpha}$ is then equivalent to the additional $-(1/2)(\partial_\mu T_{\mu\alpha})^2$, *cf.* ref. [51b, Eq.(1,2)] if one takes into account the possibility of adding total derivatives to the Lagrangian.

Thus, in the works [53, 49, 52] the contradiction between the “longitudinality” of the antisymmetric tensor field after quantization and the Weinberg theorem $B - A = \lambda$ has been partly clarified.

- D. V. Ahluwalia *et al.* developed the Majorana-McLennan-Case theory of self/anti-self conjugate states, *i. e.* of truly neutral particles, ref. [55, 28]. Complete sets of second-type spinors

$$\begin{aligned}\lambda^{S,A}(p^\mu) &\equiv \begin{pmatrix} (\zeta_\lambda^{S,A} \Theta_{[j]}) \phi_L^*(p^\mu) \\ \phi_L(p^\mu) \end{pmatrix} , \\ \rho^{S,A}(p^\mu) &\equiv \begin{pmatrix} \phi_R(p^\mu) \\ (\zeta_\rho^{S,A} \Theta_{[j]})^* \phi_R^*(p^\mu) \end{pmatrix} \end{aligned} \quad (20)$$

have been introduced there. They are *not* eigenspinors of the helicity operator of the $(j, 0) \oplus (0, j)$ representation; they describe the states which are *not* eigenstates of the Parity operator; the self/anti-self charge conjugate states form a *bi-orthonormal* set in a mathematical sense (see [28, Eqs.(41-45)] and my remark in the footnote # 2). New fundamental wave equations have been proposed in the light-front formulation of quantum field theory [55] and in the instant form [28]. As a result of this consideration it was found that they can describe fermions with the same intrinsic parities, ref. [56]. The example of such a kind of the theories has already been discussed in the old paper [57], but with type-I (Dirac) spinors. Equations for self/anti-self charge conjugate states recast into the covariant form (the “MAD” form of the Dirac equations, see also [60, 61, 43]) in ref. [58, 59]:

$$i\gamma^\mu \partial_\mu \lambda^S(x) - m\rho^A(x) = 0 \quad , \quad (21a)$$

$$i\gamma^\mu \partial_\mu \rho^A(x) - m\lambda^S(x) = 0 \quad ; \quad (21b)$$

and

$$i\gamma^\mu \partial_\mu \lambda^A(x) + m\rho^S(x) = 0 \quad , \quad (22a)$$

$$i\gamma^\mu \partial_\mu \rho^S(x) + m\lambda^A(x) = 0 \quad . \quad (22b)$$

Their possible relevance to describing neutrino and photon states has been discussed. Particularly, importance of the axial current has been stressed.

On the basis of these thoughts I am able to write the *ansatzen* substituting the de Broglie (or Jordan) *ansatz*. By the direct examination one can prove on the classical level that the 4-vector potential of different polarization states can be expressed (on using the second-type spinors) as follows:⁹

$$\begin{aligned}
 A^\mu(\mathbf{k}, +1) = & \frac{N}{m\sqrt{2}} \left\{ a_1 \left[\bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\downarrow^S(k^\mu) \right] + \right. \\
 & + a_2 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\uparrow^S(k^\mu) \right] + a_3 \left[\bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\downarrow^A(k^\mu) \right] + \\
 & + a_4 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\uparrow^A(k^\mu) \right] - a_5 \left[\bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\downarrow^A(k^\mu) \right] + \\
 & + a_6 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\uparrow^A(k^\mu) \right] - a_7 \left[\bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\downarrow^S(k^\mu) \right] + \\
 & \left. + a_8 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\uparrow^S(k^\mu) \right] \right\}. \quad (23a)
 \end{aligned}$$

$$\begin{aligned}
 A^\mu(\mathbf{k}, -1) = & -\frac{N}{m\sqrt{2}} \left\{ b_1 \left[\bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\downarrow^S(k^\mu) \right] + \right. \\
 & + b_2 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\uparrow^S(k^\mu) \right] + b_3 \left[\bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\downarrow^A(k^\mu) \right] + \\
 & + b_4 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\uparrow^A(k^\mu) \right] + b_5 \left[\bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\downarrow^A(k^\mu) \right] - \\
 & - b_6 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\uparrow^A(k^\mu) \right] + b_7 \left[\bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu (1 - \gamma^5) \lambda_\downarrow^S(k^\mu) \right] - \\
 & \left. - b_8 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu (1 + \gamma^5) \lambda_\uparrow^S(k^\mu) \right] \right\}. \quad (23b)
 \end{aligned}$$

$$\begin{aligned}
 A^\mu(\mathbf{k}, 0) = & \frac{N}{2m} \left\{ c_1 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu \lambda_\downarrow^S(k^\mu) - \bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu \lambda_\uparrow^S(k^\mu) \right] + \right. \\
 & + c_2 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu \lambda_\downarrow^A(k^\mu) - \bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu \lambda_\uparrow^A(k^\mu) \right] - \\
 & - c_3 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu \gamma^5 \lambda_\downarrow^A(k^\mu) - \bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu \gamma^5 \lambda_\uparrow^A(k^\mu) \right] - \\
 & \left. - c_4 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu \gamma^5 \lambda_\downarrow^S(k^\mu) - \bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu \gamma^5 \lambda_\uparrow^S(k^\mu) \right] \right\}. \quad (23c)
 \end{aligned}$$

⁹For the sake of the general consideration it is assumed the neutrino states to be massive.

$$\begin{aligned}
A^\mu(\mathbf{k}, 0_t) = & \frac{N}{2m} \left\{ d_1 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu \lambda_\downarrow^S(k^\mu) + \bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu \lambda_\uparrow^S(k^\mu) \right] + \right. \\
& + d_2 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu \lambda_\downarrow^A(k^\mu) + \bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu \lambda_\uparrow^A(k^\mu) \right] - \\
& - d_3 \left[\bar{\lambda}_\downarrow^S(k^\mu) \gamma^\mu \gamma^5 \lambda_\downarrow^A(k^\mu) + \bar{\lambda}_\uparrow^S(k^\mu) \gamma^\mu \gamma^5 \lambda_\uparrow^A(k^\mu) \right] - \\
& \left. - d_4 \left[\bar{\lambda}_\downarrow^A(k^\mu) \gamma^\mu \gamma^5 \lambda_\downarrow^S(k^\mu) + \bar{\lambda}_\uparrow^A(k^\mu) \gamma^\mu \gamma^5 \lambda_\uparrow^S(k^\mu) \right] \right\}. \quad (23d)
\end{aligned}$$

Of course, one can repeat the derivation of the formulas of this paper on using the Dirac 4-spinors, thus arriving at the *electron-positron theory of light*. The room of choosing the constants a_i, b_i, c_i, d_i permits us to obtain various types of (anti)commutation relations for the composite particles. Tensor currents have also been calculated. They are also composed of the second-type 4-spinors. In my opinion, resulting expressions of the type $F_\lambda^{\mu\nu} \sim \bar{\nu}_\eta (\sigma^{\mu\nu} \pm i\tilde{\sigma}^{\mu\nu}) \nu_{\eta'}$ (and its dual conjugates) also permit to construct the neutrino theory of light.

Finally, in the papers of Barut, *e.g.*, ref. [62] a self-field formulation of quantum electrodynamics have been proposed. It is based on the use of the solution

$$A_\mu(x) = \int d^4y D_{\mu\nu}(x-y) j_\nu(y) \quad (24)$$

of the coupled Maxwell-Dirac equation

$$\partial_\mu F_{\mu\nu}(x) = e \bar{\Psi}(x) \gamma_\nu \Psi(x) \quad . \quad (25)$$

$D_{\mu\nu}(x-y)$ is a Green's function of electromagnetic field in the usual potential formulation. In a series of the works A. Barut *et al.* have shown that this formulation of quantum electrodynamics (based on the iteration procedure, *not* on the perturbation theory) leads to the same experimental predictions as the ordinary formalism.

Let me try to write the formula (24) in the momentum space (To my knowledge, there were no such attempts in the literature). I consider momenta as $q = \lambda t$ and $p = (\lambda - 1)t$, λ is some function spanned from

0 to 1. In this case¹⁰

$$\begin{aligned} \mathcal{A}_\mu(x) = & -e \int \frac{d^3\mathbf{p} d^3\mathbf{q}}{(2\pi)^6} \frac{D_F((q-p)^2)}{2m\sqrt{E_p E_q}} \times \\ & \times \sum_{\sigma\sigma'} \left\{ \bar{u}_\sigma(\mathbf{p}) \gamma^\mu u_{\sigma'}(\mathbf{q}) e^{i(q-p)x} a_\sigma^\dagger(\mathbf{p}) a_{\sigma'}(\mathbf{q}) + \right. \\ & \left. + \bar{v}_\sigma(\mathbf{p}) \gamma^\mu v_{\sigma'}(\mathbf{q}) e^{-i(q-p)x} b_\sigma(\mathbf{p}) b_{\sigma'}^\dagger(\mathbf{q}) \right\} \quad , \quad (26) \end{aligned}$$

and, hence,

$$\mathcal{A}_\mu(t) = \int_0^1 d\lambda f(\lambda, t^2) \sum_{\sigma\sigma', \pm} \bar{\psi}_\sigma^\pm((\lambda-1)t) \gamma^\mu \psi_{\sigma'}^\pm(\lambda t) \quad . \quad (27)$$

Surprisingly, you may see the well-known Jordan *ansatz*. Thus, referring to the remark of the previous paragraph one can state the longitudinal de Broglie-Jordan-Barut potential can describe quantumelectrodynamic processes sufficiently good. In order to obtain transverse components of the 4-vector potential one should set up the commutation relations for the 4-spinor field, which are different from those used in the Dirac theory.

3 Questions

This paper speculates about several versions of the construction of the composite particles from states of the $(1/2, 0) \oplus (0, 1/2)$ representation space. In fact, it is a continuation of efforts undertaken in old papers, refs. [11, 13, 17, 22, 29, 30, 31, 34, 35, 62], and in the recent ones [36, 38, 40, 47, 48, 49, 50, 55, 28, 58, 59, 25]. I realize that not all the topics and not all the contradictions have been considered here. A task of this paper was mainly to give a direction for future researches and to present a basis for forthcoming publications.

Referring to phenomenological consequences of the theory, I would like to cite some paragraphs from [17a]: “... in view of the neutrino theory of light, photons are likely to interact weakly also, apart from the usual electromagnetic interactions... This assumed photon-neutrino weak interaction, if it exists, will have important bearing on astrophysics.

¹⁰It would be interesting to search physical consequences of the particular choice $\lambda = \frac{m_1}{m_1+m_2}$.

In fact, this interaction can then be held responsible for the following neutrino-generating processes in stars:

$$(1) \quad \gamma + e^- \leftrightarrow e^- + \nu + \bar{\nu} \quad , \quad (28a)$$

$$(2) \quad e^- + Z \leftrightarrow e^- + Z + \nu + \bar{\nu} \quad , \quad (28b)$$

$$(3) \quad e^- + e^+ \leftrightarrow \nu + \bar{\nu} \quad , \quad (28c)$$

$$(4) \quad \gamma + \gamma \leftrightarrow \nu + \bar{\nu} \quad , \quad (28d)$$

$$(5) \quad \gamma + \gamma \leftrightarrow \gamma + \nu + \bar{\nu} \quad , \quad (28e)$$

$$(6) \quad \Gamma \rightarrow \nu + \bar{\nu} (\Gamma \rightarrow e^- + e^+ \rightarrow \gamma \rightarrow \nu + \bar{\nu}) \quad (plasma \ process) \quad (28f)$$

... The energy dependence of the cross sections for these processes according to the present theory will be significantly different from that in other theories."

Next, I would like to put the following problems forth:

- In neutrino physics we have now most consistent indications for new physics[63, 64]. What are the origins of negative mass-squared problem from a viewpoint of the presented model? Can the solar neutrino deficit be caused by the processes mentioned above (like $\bar{\nu}\nu \rightarrow 2\gamma$)? Perhaps, we should re-calculate the age of the Sun on the basis of this model?
- Can recently observed neutrino oscillations (for a reviews see ref. [65, 58]) have some relations with the presented model?
- It is known that the Aharonov-Bohm effect, ref. [66], cannot be explained on the basis of transversal electric and magnetic fields \vec{E} and \vec{B} . Other authors applied to 4-vector potential in order to explain it. Perhaps, the possibility of dual solutions $F_{\mu\nu}$ and $\tilde{F}_{\mu\nu}$ for the spin-1 field and/or the existence of Majorana-like spinors have been missed in previous attempts? Several recent publications indicate the possibility of explanation of the Aharonov-Bohm effect on the basis of the longitudinal solutions of electromagnetism [67] (*cf.* also ref. [68]).

We are sure there exist several other problems in the modern field theory, which can be related to the matters discussed in this paper.

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