Angular momentum and torque radiated by a relativistic charged spin particle

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Abstract. In this paper two alternative definitions of density of angular momentum of electromagnetic field by Ivanenko-Sokolov and by Teitelboim are discussed. It is shown that both definitions give identical integral characteristics of radiation for an arbitrary moving relativistic charged spin particle. The total power of orbital momentum radiation is proportional to the radiation torque. The angular momentum of radiation is proportional to the kinematical Thomas spin precession. Thus, at present the dynamical interpretation of Thomas precession is obvious. As an example the angular momentum of spin light from a point magnetic momentum moving with constant velocity is studied.

1. Introduction
In 1897 A. I. Sadowsky put forward a hypothesis that circularly polarized light must posses the proper angular momentum [1]. In 1935-1936, B. A. Beth in USA [2] and A. N. S. Holborn in England [3] experimentally proved that circularly polarized light does possess angular momentum. These precise experiments not only confirmed Sadowsky’s hypothesis, but also allowed to estimate Planck’s constant accurate within 10%.
Observation of considerably greater torque became possible with the emergence of lasers (see, for example, [4]). At the present time there is no doubt about the existence of the angular momentum of circularly polarized electromagnetic waves.
However, the general definition of angular momentum of the electromagnetic field (AMEF) is argued over among physicists even nowadays [4-9].

2. Two alternative methods of the AMEF definition
It may be distinguished two alternative ways of the relativistically covariant methods for the description of AMEF [10-12].
The first method was proposed by Ivanenko and Sokolov [10] on the basis of the principle of least action for the electromagnetic field. This principle leads to the conservation laws of the density of AMEF in the differential form

\[ D_\lambda M^{\mu\nu\lambda} = 0 \]

with derivative

\[ D_\lambda = \frac{\partial}{\partial R_\lambda} = \bar{\partial}_\lambda + \vec{r}_\rho \frac{d}{d\tau} \]
where a retardation of the radiation field per time $\Delta t = \tilde{t} - t$ is taken into account. Here

$$\mathcal{M}^{\mu\nu\lambda} = \mathcal{A}^{\mu\nu\lambda} + \mathcal{J} \mathcal{T}^{\mu\nu\lambda}$$

is the density tensor of the total AMEF split into «orbital» and «spin» parts:

$$\mathcal{A}^{\mu\nu\lambda} = \frac{1}{c}(R^{\mu} T_{\nu\lambda}^{\tau} - R^{\nu} T_{\mu\lambda}^{\tau}), \quad \mathcal{J} \mathcal{T}^{\mu\nu\lambda} = \frac{1}{4\pi c} \left( A^{\mu} H^{\nu\lambda} - A^{\nu} H^{\mu\lambda} \right)$$

respectively. In addition,

$$T_{\nu\lambda}^{\mu} = -\frac{1}{4\pi} \left( \frac{1}{4} g^{\nu\lambda} H_{\alpha\beta} H^{\alpha\beta} + D^{\nu} A^{\lambda} \right) \equiv T^{\mu}$$

with $D_{\lambda} \mathcal{T}^{\nu\lambda} = 0$ is the canonical tensor of the energy density. The metrics used everywhere is $g^{\mu\nu} = \text{diag} (-1, 1, 1, 1)$. The purpose of the quotes presence in our notations is due to the fact that the derivative $D_{\lambda} \mathcal{A}^{\mu\nu\lambda} = T_{\nu\lambda}^{\mu} - T_{\mu\lambda}^{\nu}$ is nonzero. This happens because the canonical tensor $T_{\nu\lambda}^{\mu}$ isn’t symmetrical and, therefore, the separation of $\mathcal{M}^{\mu\nu\lambda}$ into «orbital» and «spin» parts isn’t relativistically invariant. Worse than that, $T_{\nu\lambda}^{\mu}$ isn’t gauge invariant, so that $\mathcal{J} \mathcal{T}^{\mu\nu\lambda}$ isn’t gauge invariant either and this means that it can’t claim to be the real observed value. In this connection the definition of the proper AMEF or spin

$$\Pi = \frac{1}{4\pi c} \int [E A] \, dV$$

is required in additional substantiation.

Alternative pathway is the density tensor of the total AMEF proposed by C. Teitelboim [11]

$$\mathcal{M}^{\mu\nu\lambda} = \frac{1}{c}(R^{\mu} T_{\nu\lambda} - R^{\nu} T_{\mu\lambda})$$

on basis of the symmetric density tensor of the electromagnetic field energy

$$T_{\nu\lambda} = -\frac{1}{4\pi} \left[ \frac{1}{4} g^{\nu\lambda} H_{\alpha\beta} H^{\alpha\beta} + H^{\mu\nu} H_{\rho}^{\lambda} \right] \equiv T^{\mu}$$

which possesses gauge-invariance in contrast to the $T_{\nu\lambda}^{\mu}$. Tensor $T^{\nu\lambda}$ is calculated according to C. Teitelboim in terms of radiation theory of relativistic particles in which $H^{\mu\nu} = \overline{H}^{\mu\nu} + \overline{\overline{H}}^{\mu\nu}$, where $\overline{H}^{\mu\nu} \sim 1/\tilde{r}^2$ is the well-known strength tensor of the attached fields in the near-charge zone and $\overline{\overline{H}}^{\mu\nu} \sim 1/\tilde{r}$ is in the long-distance region which is called the radiation zone. The four-dimensional vector $\tilde{r}^{\mu}(\tau, \tilde{t}) = R^{\mu}(\tilde{t}) - r^{\mu}(\tau)$ traced from the trajectory radius-vector $r^{\mu}(\tau)$ in proper time $\tau$ to the spectator point of four-dimensional vector $R^{\mu}(\tilde{t})$. Now the decomposition of the density of total AMEF into orbital and spin parts arise automatically. Tensor $T_{\nu\lambda}^{\mu}$ decomposes into three parts in agreement with the general theory of relativistic radiation $T_{\nu\lambda}^{\mu} = \overline{T}_{\nu\lambda}^{\mu} + \tilde{T}_{\nu\lambda}^{\mu} + \overline{\overline{T}}_{\nu\lambda}^{\mu}$, where $\overline{T}_{\nu\lambda}^{\mu}$ is the energy density tensor of the convection field in the near-charge zone, $\tilde{T}_{\nu\lambda}^{\mu}$ is the energy density tensor of the mixed fields, $\overline{\overline{T}}_{\nu\lambda}^{\mu}$ is the energy density tensor of the radiation field in the wave zone.

In the following we will consider the AMEF only in the wave zone, for which
In terms of the derivative of a retarded function it can be shown that \( D_\lambda \tilde{T}^{\nu\lambda} = 0 \), and also
\[
D_\lambda \left( \tilde{T}^{\nu\lambda} + \tilde{T}^{\nu\lambda} \right) = 0, \quad D_\lambda \tilde{T}^{\mu\lambda} = 0.
\]
From this one can obtain \( D_\lambda \tilde{A}^{\mu\lambda} = 0 \), \( D_\lambda \tilde{\Pi}^{\mu\lambda} = 0 \), and as a consequence \( D_\lambda \tilde{M}^{\mu\lambda} = 0 \).
Thus, the decomposition of the density of the total AMEF onto orbital and spin parts is now gauge and relativistically invariant.

3. Relativistic theory of the AMEF radiation
First we write expressions for the density tensors of orbital momentum in explicit form with regard to the wave zone and the density tensor of the spin momentum. Now we can obtain orbital and spin momenta of the radiation field on basis of Gauss’s integral theorem in the form
\[
\tilde{L}^{\mu\nu} = \oint A^{\mu\nu} d\sigma_\lambda, \quad \tilde{\Pi}^{\mu\nu} = \oint \Pi^{\mu\nu} d\sigma_\lambda.
\]
Here \( d\sigma_\lambda = e_\lambda \varepsilon^2 c d\tau d\Omega_0 \) is an element of spacelike hypersurface with the normal unit vector
\[
e_\lambda = -c \frac{\vec{r}_\lambda}{\vec{v}^\mu} - \frac{\vec{v}_\lambda}{c}
\]
with \( v^\mu = dr^\mu/d\tau \), and \( d\Omega_0 \) is a solid angle element in the rest frame of the particle. Integrating \( \tilde{L}^{\mu\nu} \) and \( \tilde{\Pi}^{\mu\nu} \) over the angles in the rest frame by well-known (see [12]) integrals we can obtain expressions for the power of the orbital and spin AMEF radiation in the wave zone
\[
\frac{d\tilde{L}^{\mu\nu}}{d\tau} = \frac{2e^2}{3c^5} \overrightarrow{w}_\mu \overrightarrow{w}_\nu \left( r^\mu v^\nu - r^\nu v^\mu \right), \quad \frac{d\tilde{\Pi}^{\mu\nu}}{d\tau} = \frac{2e^2}{3c^3} \left( v^\mu \overrightarrow{w}_\nu - \overrightarrow{v}_\mu \overrightarrow{w}_\nu \right)
\]
where \( \overrightarrow{w}_\mu = d\overrightarrow{v}_\mu /d\tau \).
Our formulas have clear-cut physical interpretation. If we put the well-known charge power of the radiation into operation [13] \( d\tilde{P}^{\mu}/d\tau = \left( 2e^2/3c^5 \right) \overrightarrow{w}_\mu \overrightarrow{v}_\nu \overrightarrow{v}_\mu \), then we can get the expression for the orbital momentum of radiation
\[
\frac{d\tilde{L}^{\mu\nu}}{d\tau} = r^\mu \frac{d\tilde{P}^{\nu}}{d\tau} - r^\nu \frac{d\tilde{P}^{\mu}}{d\tau} = \frac{d}{d\tau} (r^\mu \tilde{P}_\nu - r^\nu \tilde{P}_\mu),
\]
which is exactly same relation between the torque tensor of the particle and its angular momentum tensor derivative as in the relativistic mechanics \( \tilde{F}^{\mu\nu} = r^\mu \tilde{F}_\nu - r^\nu \tilde{F}_\mu = d\tilde{L}^{\mu\nu} /d\tau \). Thus, the radiation of the orbital AMEF adds up to the radiation of the field momentum of the force.
The power of the radiation of the spin momentum is proportional to the Thomas’s precession frequency \( \Omega_{\text{Th}}^{\mu\nu} \) which is defined by this equation in the relativistic spin theory (see. [12])
\[
\left( \frac{d\pi^{\mu}}{d\tau} \right)_{\text{Th}} = \frac{1}{c^2} \left( v^\mu \overrightarrow{w}^\nu - \overrightarrow{v}_\mu \overrightarrow{w}_\nu \right) \pi^\nu = \Omega_{\text{Th}}^{\mu\nu} \pi^\nu,
\]
where \( \pi^\mu \) is a well-known four-dimensional space-like spin vector. This shows that the Thomas precession, which until now was known as purely kinematic relativistic effect, becomes obvious dynamic interpretation.
4. Spin light radiation

The spin light [13] corresponds to the electromagnetic radiation of a relativistic spin particle with a proper magnetic momentum. Such radiation arises only from the electrically neutral particles (neutrons [14], neutrino [15]). If these particles have also an electrical charge besides the magnetic momentum, the interference of radiations from the accelerated charge and from the proper magnetic momentum arises. This phenomenon is the most noticeably observed just by extreme electron’s energies in the synchrotron accelerators [16]. The radiation associated with the spin leads to the radiative self-polarization of relativistic electrons known as Sokolov-Ternov effect [17, 18]. In what follows the problem of identification of the spin light against the background of powerful synchrotron radiation, of recoil effects and of other relativistic phenomena was studied in details on the basis of the semiclassical theory of relativistic radiation [13, 19].

At the present time spin light as a special type of electromagnetic radiation is discussed in the case not only of synchrotron and undulator radiation of electrons [13, 19-21], but also in the case of high energy neutrino radiation in matter and in gravitational fields [21-24].

For the construction of our theory we will use a well-known method of the classical radiation theory of relativistic particles [11, 13 and 19].

As starting relations for the consideration of AMEF of the spin light we use already known four-dimensional vector-potentials $A_\mu^e$ and $A_\mu^m$, which obtained on the basis of the Lienard-Viehert potentials for electric charge and the Hertz’s tensor-potential for the proper magnetic dipole of the particle

$$A_\mu^e = -e \frac{D_\mu}{\rho_\mu U_\rho}, \quad A_\mu^m = \overline{A}_\mu^m + \tilde{A}_\mu^m,$$

$$\overline{A}_\mu^m = c^3 \frac{\Pi_{\mu\nu}\dot{\rho}_\nu}{(\rho_\mu U_\rho)^3}, \quad \tilde{A}_\mu^m = -c \left[ \frac{\Pi_{\mu\nu}\dot{\rho}_\nu}{(\rho_\mu U_\rho)^2} - \frac{\Pi_{\mu\nu\lambda}\dot{\rho}_\nu}{(\rho_\mu U_\rho)^2} \right].$$

Here index $e$ refers to the charge and $m$ - to the magnetic momentum respectively. Symbol $\circ$ means a derivative with respect to proper time $\tau$.

The stress tensor of electromagnetic field is defined according to the general rule

$$H^{\mu\nu} = D^{\mu} A^{\nu} - D^{\nu} A^{\mu}.$$ 

With given expressions of vector potentials and in accordance with definitions of the stress tensor and retarded derivative it’s possible to find the field strengths

$$H^{\mu\nu}_{e} = \overline{H}^{\mu\nu}_{e} + \tilde{H}^{\mu\nu}_{e},$$

$$\overline{H}^{\mu\nu}_{e} = ec^2 \frac{\rho^{[\mu} W^{\nu]} \dot{\rho}^{\mu}}{(\rho_\mu U_\rho)^3}, \quad \tilde{H}^{\mu\nu}_{e} = e \left\{ -\frac{\rho^{[\mu} W_{\nu]} \dot{\rho}^{\mu}}{(\rho_\mu U_\rho)^2} + \frac{\rho^{[\nu} W_{\mu]}}{(\rho_\mu U_\rho)^2} \right\}$$

- for the charge, and

$$H^{\mu\nu}_{m} = \overline{H}^{\mu\nu}_{m} + \tilde{H}^{\mu\nu}_{m} + \hat{H}^{\mu\nu}_{m},$$
- for the magnetic moment. Here a bracket denotes antisymmetrization: $\langle a^\mu b^\nu \rangle = a^\mu b^\nu - a^\nu b^\mu$.

Unlike to the charge strength, the tensor of the magnetic momentum consists of three parts: the convection field with $H_m^{\mu\nu} \sim 1/r^3$, the radiation field with $H_m^{\mu\nu} \sim 1/r$ and the mixed field $H_m^{\mu\nu} \sim 1/r^3$.

Since the fields caused by the electrical charge are well-known in the literature (see. [11, 13 and 19]), so in the following we’ll pay more attention to the tensor $H_m^{\mu\nu}$.

In spite with the complexity of the fields given above, it can be verified to satisfy the first pair of Maxwell’s equations. In the retarded form these equations have the following form

$$0 = \nabla^\rho (D^\rho H_m^{\mu\nu}) + \nabla^{\nu} (D^\nu H_m^{\mu\rho} + D^\rho H_m^{\nu\mu}) = 0.$$

The second pair of Maxwell’s equations are, again, valid on the world line of the particle

$$D^\nu H_m^{\mu\nu} = 0.$$

It should be emphasized that the first pair of Maxwell’s equations is valid independently over all terms with the same derivatives with respect to $\tau$. In contrast to the second pair. It should be noted that both of the invariants of magneton electromagnetic field in the wave zone are vanished (as expected in the case of the radiation field of charge).

5. Symmetrical stress tensor of spin light

A dynamic characteristic to define the stress tensor of AMEF is a symmetrical stress tensor of energy of spin light [25]

$$T^{\mu\lambda} = -\frac{1}{4\pi} \left( \frac{1}{4} g^{\mu\lambda\alpha\beta} H_{\alpha\beta} H^{\rho\alpha\beta} + H^{\mu\rho} H^{\nu}_{\rho} \right).$$

In general this tensor for the charge fields and for the magnetic momentum fields consists of five terms

$$T^{\mu\nu} = (-6) T^{\mu\nu} + (-5) T^{\mu\nu} + (-4) T^{\mu\nu} + (-3) T^{\mu\nu} + (-2) T^{\mu\nu}.$$
In the following we will consider the pure spin light and the charge radiation will be taken into account only in the mixed fields not far from the wave zone of radiation. With respect to this assumption the components of the stress tensor of the spin light we need are the follows

\[ (-3) \mathcal{T}^{\mu\nu} = -\frac{1}{4\pi} \left[ \widetilde{H}_m^{\mu\rho} \widetilde{H}_{\rho m}^{\nu} + \widetilde{H}_e^{\mu\rho} \widetilde{H}_{\rho m}^{\nu} + \widetilde{H}_m^{\mu\rho} \widetilde{H}_e^{\nu} + \nu, \mu \right], \]

\[ (-2) \mathcal{T}^{\mu\nu} = -\frac{1}{4\pi} \left[ \widetilde{H}_m^{\mu\rho} \widetilde{H}_{\rho m}^{\nu} + \widetilde{H}_e^{\mu\rho} \widetilde{H}_{\rho m}^{\nu} + \nu, \mu \right], \]

All the invariants of the electromagnetic field which symmetrical stress tensor contains

\[ \widetilde{H}_{\alpha\beta\mu} \widetilde{H}_{\mu\nu} \widetilde{H}_{\alpha\beta} + \nu, \mu \]

are zeros according to our hypothesis. With the field strengths in the case of the uniform motion of the charged magneton \((v^\mu = \text{const}, w = \dot{w} = 0)\) we find \((-2) \mathcal{T}^{\mu\nu}_e = 0\) and

\[ (-3) \mathcal{T}^{\mu\nu}_m = (-3) \mathcal{T}^{\mu\nu}_m + (-3) \mathcal{T}^{\mu\nu}_{em}, \]

where

\[ (-3) \mathcal{T}^{\mu\nu}_m = -\frac{1}{4\pi} \left[ \widetilde{H}_m^{\mu\rho} \widetilde{H}_{\rho m}^{\nu} + \nu, \mu \right], \]

\[ (-2) \mathcal{T}^{\mu\nu}_m = -\frac{1}{4\pi} \widetilde{H}_m^{\mu\rho} \widetilde{H}_{\rho m}^{\nu}. \]

In the explicit form these formulas correspond to

\[ (-3) \mathcal{T}^{\mu\nu}_m = -\frac{c^2}{2\pi} \left[ \tilde{r}^{(\mu}_\rho \Sigma^{\nu)\alpha} \tilde{\rho}_{\alpha} + \frac{\tilde{r}^{(\mu}_\rho \Sigma^{\nu)\alpha} \tilde{\rho}_{\alpha}}{(\tilde{\rho}^{(\mu}_\rho \Sigma^{\nu)\alpha})^3} + \frac{3c^2}{\tilde{\rho}^{(\mu}_\rho \Sigma^{\nu)\alpha}} \tilde{\rho}_{\alpha} \right], \]

\[ (-3) \mathcal{T}^{\mu\nu}_{em} = \frac{ec^2}{4\pi} \left( \tilde{r}^{(\mu}_\rho \Sigma^{\nu)\alpha} \tilde{\rho}_{\alpha} \right), \]

\[ (-3) \mathcal{T}^{\mu\nu}_m = -\frac{c^2}{4\pi} \left( \tilde{r}^{(\mu}_\rho \Sigma^{\nu)\alpha} \tilde{\rho}_{\alpha} \right) \tilde{\rho}_{\rho}. \]

Here round brackets mean symmetrisation \(a^{(\mu}_\rho b^{\nu)} = a^{\mu} b^{\nu} + a^{\nu} b^{\mu}\). It is noteworthy that in all these cases \((-3) \mathcal{T}^{\mu\nu}_e = \mathcal{T}^{\mu\nu}_m = 0\).

6. Orbital and proper AMEF of spin light

With respect to Teitelboim’s assumption [11] the full spin stress tensor AMEF is defined like

\[ \mathcal{M}^{\mu\nu\lambda} = \frac{1}{c} \left( \tilde{r}^{(\mu}_\rho \Sigma^{\nu)\alpha} \tilde{\rho}_{\alpha} \right). \]

The division of the full AMEF into orbital and spin parts has gauge and relativistic invariance in opposed to the traditional formulation (see Sec.2):

\[ \mathcal{M}^{\mu\nu\lambda} = \mathcal{A}^{\mu\nu\lambda} + \mathcal{J}^{\mu\nu\lambda}. \]
Then we will consider AMEF located at the wave zone, where

\[ \tilde{\mathcal{A}}^{\mu\nu\lambda} = \frac{1}{c} \left( r^{\mu\nu} T^{\nu\lambda}_{(-2)} - r^{\nu\mu} T^{\mu\lambda}_{(-2)} \right), \quad \tilde{T}^{\mu\nu\lambda} = \frac{1}{c} \left( r^{\mu\nu} T^{\nu\lambda}_{(-3)} - r^{\nu\mu} T^{\mu\lambda}_{(-3)} \right). \]

Using \((-2)_\lambda T^{\mu\nu}\) spin stress tensor \(\tilde{T}^{\mu\nu\lambda}\) vanishes and the first nonzero term is \((-3)_\lambda T^{\mu\nu}\).

The formulas written above are very cumbersome that is why we’ll deal with the uniform motion of the charged magneton. Moreover, according to relations \(\nu^\mu = const, w = \bar{w} = 0\) may be written

\[ \Pi^{\mu\nu} \nu^\mu = \bar{\Pi}^{\mu\nu} \nu^\mu = \bar{\Pi}^{\mu\nu} \nu^\mu = 0, \]

as follows from the spacelikeness of tensor \(\Pi^{\mu\nu}\).

Then we can find the stress tensor of the orbital momentum. In a similar fashion we can consider also the spin AMEF. For the uniform motion of the magnetic momentum in the wave zone the stress tensor of the orbital and spin AMEF is defined in accordance with

\[ \tilde{\mathcal{A}}^{\mu\nu\lambda}_m = -\frac{c}{4\pi} \tilde{r}_\alpha \tilde{\Pi}^{\alpha\beta\gamma} \tilde{\Pi}^{\beta\gamma\lambda} - \frac{1}{2\pi} \left( \tilde{r}_\alpha \tilde{\Pi}^{\alpha\beta\lambda} \right) \tilde{\Pi}^{\beta\gamma\lambda}. \]

It is easy to see that in the wave zone \(D_\lambda \tilde{\mathcal{A}}^{\mu\nu\lambda}_m = 0, D_\lambda \tilde{T}^{\mu\nu\lambda}_m = 0\) and from this all the radiation of the orbital AMEF off the world line moves through the spacelike plane with a surface element \(d\sigma_\lambda\) (see Sec.2).

Integrating in this relation over \(d\sigma_\lambda\), taking well-known angular integrals into account (see Sec.3) we can get a radiation power of the orbital and spin AMEF independent on the reference frame

\[ \frac{d\bar{L}^{\mu\nu}_m}{d\tau} = \frac{1}{3c^3} \bar{\Pi}^{\alpha\beta\gamma} (r^{\mu\nu} \nu^\gamma - r^{\nu\mu} \nu^\gamma) \quad \frac{d\bar{\Pi}^{\mu\nu}_m}{d\tau} = -\frac{2}{3c^3} \left( \bar{\Pi}^{\alpha\mu\nu} \bar{\Pi}^{\alpha\nu\mu} - \bar{\Pi}^{\mu\nu\alpha} \bar{\Pi}^{\nu\mu\alpha} \right). \]

It is obvious that this magnitude is proportional to the tensor of angular momentum of this very particle \(P^{\mu\nu} = r^{\mu\nu} \nu^\gamma - r^{\nu\mu} \nu^\gamma\). In the case of the uniform motion all the components are vanished. Thus \(d\bar{L}^{\mu\nu}_m/d\tau = 0\). Note that in the case of the mixed radiation of the orbital AMEF is also vanish due to \(\bar{H}^\mu_\nu = 0\).

Similarly we can construct the stress tensor AMEF for mixed radiation

\[ \tilde{T}^{\mu\nu\lambda}_m = \frac{ec^2}{4\pi} \tilde{r}_\alpha \tilde{\Pi}^{\alpha\beta\lambda} \tilde{\Pi}^{\beta\gamma\lambda}, \]

and again from \(D_\lambda \tilde{T}^{\mu\nu\lambda}_m = 0\), the total AMEF power of interferential radiation is

\[ \frac{d\bar{\Pi}^{\mu\nu}_m}{d\tau} = \frac{2e^2}{3c^3} \bar{\Pi}^{\mu\nu}_m. \]
7. Conclusion
Thus, in this work two alternative definitions of density of intrinsic angular momentum of electromagnetic field by Ivanenko-Sokolov and by Teitelboim are discussed. It is shown that in spite of the absence of the outward sign of similarity both definitions give identical integral characteristics of radiation for an arbitrary moving relativistic charge. The total power of orbital momentum radiation is proportional to the relativistic angular momentum of the particle, and corresponds to the radiation torque. The spin angular momentum of radiation is proportional to the kinematical Thomas spin precession, which becomes obvious dynamical interpretation.

To sum up, it can be stated that this work has discovered a new trend in the relativistic theory of radiation and the spin properties of relativistic particles. In this paper we also demonstrate a new phenomenon of nature – the proper angular momentum of electromagnetic of spin light radiation.

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References
[1] Sadowsky A I 1987 Zhurn. Russ. Fiz.-Khim. Ob.-va, Fiz. I, Vyp. 2 82 (in Russian) see also 1899 Acta et Comment. Imp. Univ. Jurien 7, No. 1-2 (in French)
[2] Beth B A 1935 Phys. Rev. 48 471; 1936 50 115
[3] Holborn A N S 1936 Nature 137 31
[4] Akhmanov S A and Nikitin S Yu 1998 Fiz. Optica (MSU, Moskow) (in Russian)
[5] Ohanian H C 1986 Amer. J. Phys. 54 500
[6] Wulfson K S 1987 Usp. Fiz. Nauk 152 668
[7] Sokolov I V 1991 Usp. Fiz. Nauk 161 175
[8] Barabanov A L 1993 Usp. Fiz. Nauk 163 75
[9] Rosenberg G V 1950 Usp. Fiz. Nauk 40 328 (in Russian)
[10] Ivanenko D D and Sokolov A A 1949 Classical Field Theory (GITTL, Moskow-Leningrad), in Russian; see also 1953 Klassische Feld theorie (Akademie-Verlag, Berlin), in German
[11] Teitelboim C and Villarroel D 1980 Nuovo Cim. 3 1
[12] Ch. G. van Weert 1973 Physica 65 452
[13] Bordovitsyn V A, Ternov I M and Bagrov V G 1995 Usp. Fiz. Nauk 165 1083
[14] Ternov I M, Bagrov V G and Khapaev A M 1965 JETP 48 961
[15] Lobanov A E and Studenikin A I 2003 Phys. Lett 564B 27
[16] Bondar A E and Saldin E L 1982 Nucl. Instrum. Meth 195 577
[17] Sokolov I V and Ternov I M 1963 Dokl. Akad. Nauk 153 1052
[18] Ternov I M 1995 Usp. Fiz. Nauk 38 1037
[19] Synchrotron Radiation Theory and its Development 1999 In Memory of I. M. Ternov. ed. V. A. Bordovitsyn (World Scientific, Singapore)
[20] Kulipanov G N, Bondar A E, Bordovitsyn V A et al 1995 Nucl. Instrum. Meth 359A 34
[21] Bordovitsyn V and Epp V Ya 1998 Nucl. Instrum. Meth 405A 220
[22] Lobanov A E 2006 J Phys. 39A 7517; 2005 Phys. Lett 619B 136
[23] Grigoriev A, Shinkevich S and Studenikin A 2006 Particle Physics at the year of 250th Lomonosov Conf. on Element. Particle Physics ed. by A. Studenikin, (World Scientific, Singapore)
[24] Dvornikov M, Grigoriev A and Studenikin A 2005 Int. J. Mod. Phys. 14D 309