A rotating electric dipole radiates spin and orbital angular momentum

R. I. Khrapko
Moscow Aviation Institute, 125993, Moscow, Russia

According to the standard electrodynamics, a rotating electric dipole emits angular momentum mainly into the equatorial part of space situated near the plane of the rotation where polarization of the radiation is almost linear. Polar regions situated near the axis of rotating are scanty by the angular momentum, although they are intensively illuminated by the almost circularly polarized radiation, which must carries spin angular momentum. A conclusion is made that the electrodynamics sights orbital angular momentum only and overlooks spin. This means that the electrodynamics is not complete. We introduce a spin tensor into the electrodynamics and calculate the whole angular momentum flux radiated by the dipole.
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1. Introduction and conclusions

According to the standard electrodynamics [1], a rotating electric dipole p radiates time-average electromagnetic power[1]

$$\mathsf{P} = d\mathsf{E}/dt = \omega^4 p^2 / 6\pi \tag{1.1}$$

and angular momentum flux, i.e. torque

$$\underset{L}{\tau} = dL/dt = \omega^3 p^2 / 6\pi \tag{1.2}$$

where E and L are the energy and angular momentum. Below we set $p = 1$, the speed of light $c = 1$, and $\varepsilon_0 = 1$.

The power (1) can be readily obtained by integrating

$$\mathsf{P} = <\oint \mathbf{E}\times\mathbf{B}\cdot\mathbf{da}> = \int \omega^4(\cos^2\theta + 1)\sin\theta\, d\theta d\varphi / 32\pi^2 = \omega^4/6\pi \tag{1.3}$$

where $\mathbf{E}\times\mathbf{B}$ is the Poynting vector and $\mathbf{da} = \hat{\mathbf{r}}\, r^2 \sin\theta\, d\theta d\varphi$ is a surface element ($\hat{\mathbf{r}} = \mathbf{r}/r$). However, the torque (1.2) is obtained not so trivially. The standard expression [2] that is a moment of the Poynting vector gives zero,

$$\mathbf{r}\times(\mathbf{E}\times\mathbf{B})\cdot\mathbf{da} = 0, \tag{1.4}$$

because of a collinearity of $\mathbf{r}$ and $\mathbf{da}$. A right way of calculating the angular momentum flux is presented at [3].

We must use a component of Maxwell energy-momentum tensor. $T^{ij}da_j = dP^i/dt$ is a momentum flux across the surface element da_j, and $2r^{[k}T^{i]j}da_j = d\underset{L}{\tau}^{ki}$ is the angular momentum flux across da_j. But the angular momentum flux relative to z-axis is a three-vector $3\hat{z}^{[l}d\underset{L}{\tau}^{ki]}$, which must be dualized:

$$\hat{z}^l d\underset{L}{\tau}^{ki}\sqrt{g}\, e_{lki}/2 = d\underset{L}{\tau}_z. \tag{1.5}$$

Here $\hat{z}^l$ is the unite z-coordinate vector and $\sqrt{g}\, e_{lki}$ is the antisymmetric tensor. The calculating yields

$$\underset{L}{\tau}_z = dL_z/dt = \oint \hat{z}^l r^k T^{ij}\sqrt{g}\, e_{lki} da_j = \int \omega^3 \sin^3\theta\, d\theta d\varphi / 16\pi^2 = \omega^3/6\pi. \tag{1.6}$$

This radiation is elliptically polarized. The ratio of lengths of the half-axes equals to

$$\cos\theta. \tag{1.7}$$

[1] A. Corney erroneously wrote [2] that the total power radiated by an oscillating electric dipole moment, p, is $\mathsf{P} = \omega^4 p^2/12\pi$ in both cases, for the case of circular oscillation and for the case of linear oscillation. But his Fig. 1(d) is correct.

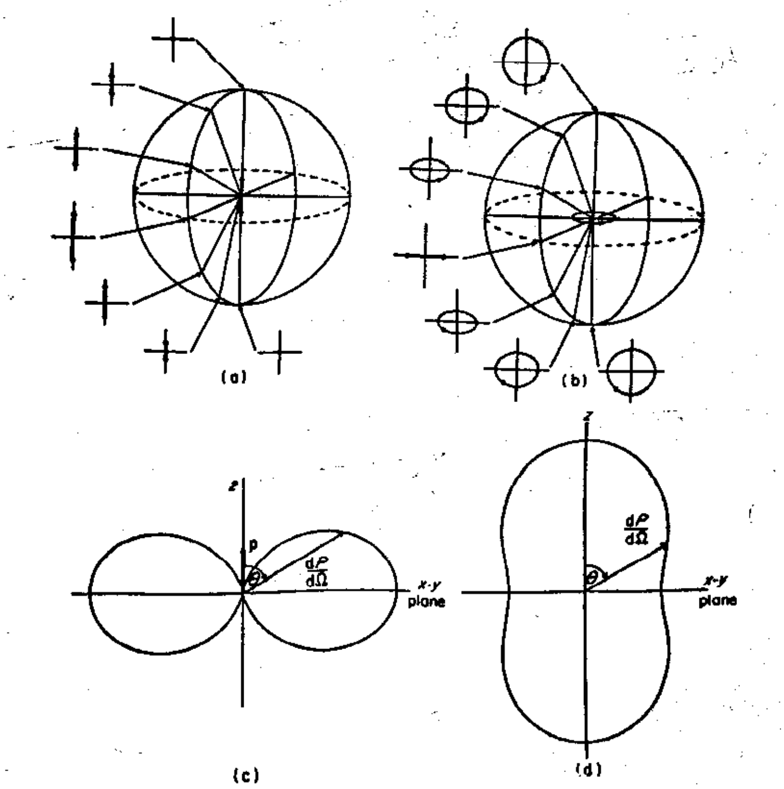

FIG. 13. **The angular distribution and the polarization for electric dipole radiation. [Adapted from Corney, A. (1977). "Atomic and Laser Spectroscopy." Oxford University Press, Oxford.]**

Fig. 1

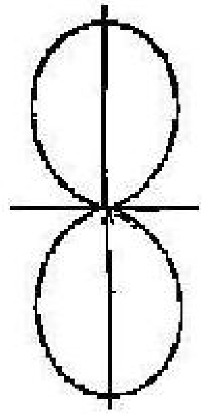

Fig. 2
The angular distribution of spin flux for a circular oscillator

In particular, the *z*-directed ($\theta = 0$) radiation is circularly polarized, and the radiation in the equatorial plane $(\theta = \pi/2)$ is linearly polarized. The polarization and the angular distribution of power (1.1), (1.3),

$$dP/d\Omega = \omega^4(\cos^2\theta + 1)/32\pi^2\,, \tag{1.8}$$

is depicted in Fig. 1(b) and Fig. 1(d) [4]. The angular distribution of the angular momentum flux relative to z-axis, according to (1.6), is

$$d\tau_{L\,z}/d\Omega = \omega^3 \sin^2/16\pi^2\,, \tag{1.9}$$

where $d\Omega = \sin\theta\, d\theta d\varphi$. This distribution coincides in shape with Fig. 1(c).

But, there is a puzzle here. These show that the angular momentum is emitted mainly into the equatorial part of space, situated near the plane of the rotation where, according to (1.7), the polarization is elliptic or linear. Polar regions, situated near the *z*-axis, are scanty by the angular momentum, although they are intensively illuminated by the almost circularly polarized radiation.

However, R. Feynman, telling about a spin of photons, clearly shows [5] that when a circularly polarized wave is absorbed the absorbing medium gets angular momentum and energy in a $1/\omega$ ratio because a circularly polarized wave carries spin angular momentum.

From our viewpoint, this means that the angular momentum (1.2), (1.6) is an orbital angular momentum unconnected with spin of electromagnetic field. This angular momentum, possibly, has no wave nature because the Poynting vector may be not bound to have a wave nature. If rotation of a dipole is stationary, a torque applied to the dipole must compensate the radiated power (1.1)

$$P = \tau\omega \tag{1.10}$$

This torque is emitted into the equatorial region as orbital angular momentum flux.

From our viewpoint, the angular momentum (1.2), (1.6) does not exhaust the reality. Actually, the polar regions, illuminated by the circularly polarized light, get a certain amount of spin angular momentum. But calculating of this angular momentum calls for a spin tensor of electromagnetic waves.

Electron spins of material of the dipole may be sources of the spin radiation. The electron spins are gradually oriented in parallel to *z*-axis during the radiation. In other words, a rotating dipole is being magnetized in the transverse direction. A demagnetization of the dipole requires an additional torque applied to the dipole.

2. Calculation of the power and the orbital angular momentum

Here we detail eqns. (1.3) and (1.6). The **E** and **B** field satisfy equations [2, 6]:

$$4\pi E^i = 3p^k r_k r^i / r^5 - p^i / r^3 + 3\dot{p}^k r_k r^i / r^4 - \dot{p}^i / r^2 + \ddot{p}^k r_k r^i / r^3 - \ddot{p}^i / r, \tag{2.1}$$

$$4\pi B_{ik} = 2\dot{p}_{[i} r_{k]} / r^3 + 2\ddot{p}_{[i} r_{k]} / r^2. \tag{2.2}$$

We use spherical coordinate system $x^1 = r,\ \ x^2 = \theta,\ \ x^3 = \varphi,$ with the metric

$$g_{11} = 1, \quad g_{22} = r^2, \quad g_{33} = r^2 \sin^2\theta, \quad \sqrt{g} = r^2 \sin\theta. \tag{2.3}$$

The unit vector **p** has Cartesian components $p^x = \exp(-i\omega t),\ \ p^y = i\exp(-i\omega t),\ \ \ p^z = 0$, and spherical components:

$$p^i = \{p^r = \sin\theta,\ p^\theta = (\cos\theta)/r,\ p^\varphi = i/(r\sin\theta)\}\exp[i(\varphi - \omega t)] \tag{2.4}$$

$$p_i = \{p_r = \sin\theta,\ p_\theta = r\cos\theta,\ p_\varphi = i\, r\sin\theta\}\exp[i(\varphi - \omega t)] \tag{2.5}$$

The **E** and **B** fields are

$$E^r = (2/r^3 - i2\omega/r^2)\sin\theta\, \exp[i\varphi + i\omega(r-t)]/4\pi, \tag{2.6}$$

$$E^\theta = (-1/r^4 + i\omega/r^3 + \omega^2/r^2)\cos\theta\, \exp[i\varphi + i\omega(r-t)]/4\pi, \tag{2.7}$$

$$E^\varphi = (-i/r^4 - \omega/r^3 + i\omega^2/r^2)\exp[i\varphi + i\omega(r-t)]/(4\pi\sin\theta), \tag{2.8}$$

$$B_{r\theta} = (i\omega/r + \omega^2)\cos\theta\, \exp[i\varphi + i\omega(r-t)]/4\pi, \tag{2.9}$$

$$B_{\varphi r} = (\omega/r - i\omega^2)\sin\theta\, \exp[i\varphi + i\omega(r-t)]/4\pi, \quad B_{\theta\varphi} = 0. \tag{2.10}$$

r-component of the Poynting vector, i.e. T^{0r}-component of the Maxwell tensor, is

$$T^{0r} = E^\theta B_{r\theta} - E^\varphi B_{\varphi r}. \tag{2.11}$$

Using the higher powers of *r*, we obtain the time average quantity:

$$< T^{0r} >= \Re\{E^\theta B^*_{r\theta} - E^\varphi B^*_{\varphi r})/2 = \omega^4(\cos^2\theta + 1)/(32\pi^2 r^2) \tag{2.12}$$

in according to (1.3).

The component $T^{\varphi r}$ of the Maxwell tensor is

$$T^{\varphi r} = B_{r\theta} B^{\varphi\theta} - E_r E^\varphi = -E^r E^\varphi. \tag{2.13}$$

The time average quantity is

$$< T^{\varphi r} >= \Re\{-E^r (E^\varphi)^*\}/2 = \omega^3/(16\pi^2 r^4). \tag{2.13}$$

The unit vector $\hat{\mathbf{z}}$ has spherical components

$$\hat{z}^r = \cos\theta,\ \hat{z}^\theta = -(\sin\theta)/r,\ \hat{z}^\varphi = 0 \tag{2.14}$$

Using (1.5) yields (1.6) because $e_{\theta r\varphi} = -1$,

$$\underset{L}{\tau}{}_z = \oint \hat{z}^\theta r < T^{\varphi r} > \sqrt{g}\, e_{\theta r\varphi} da_r = \int \omega^3 \sin^3\theta\, d\theta d\varphi/(16\pi^2) = \omega^3/(6\pi). \tag{2.15}$$

3. Radiation of spin

In this section we use an electromagnetic spin tensor of the form [7 – 11] (see also the Appendix)

$$\Upsilon^{\lambda\mu\nu} = \underset{e}{\Upsilon}{}^{\lambda\mu\nu} + \underset{m}{\Upsilon}{}^{\lambda\mu\nu} = A^{[\lambda}\nabla^{|\nu|}A^{\mu]} + \Pi^{[\lambda}\nabla^{|\nu|}\Pi^{\mu]}, \quad \lambda, \mu, \nu, ... = 0, 1, 2, 3. \tag{3.1}$$

Here A^λ, Π^λ are the magnetic and electric vector potentials,

$$F_{\mu\nu} = 2\partial_{[\mu}A_{\nu]}, \quad \Pi_\alpha = e_{\alpha\lambda\mu\nu}\Pi^{\lambda\mu\nu}, \quad \partial_\nu \Pi^{\lambda\mu\nu} = F^{\lambda\mu}. \tag{3.2}$$

Because of spherical coordinates we use covariant derivatives in (3.1).

The sense of the spin tensor is presented by the equation for a spin flux, d^3S^{ij}/dt, across the surface element da_k, i.e. for a spin torque on the element da_k,

$$\Upsilon^{ijk} da_k = d^3S^{ij}/dt = d\underset{S}{\tau}{}^{ij}. \tag{3.3}$$

Now we calculate the spin radiation of the rotating dipole.

We set $A_0 = \phi = 0$. So, $A^i = -\int E^i dt = -iE^i/\omega$. Similarly, $\Pi^i = \int B^i dt = iB^i/\omega$, where

$$B^\theta = e^{\theta\varphi r} B_{\varphi r}/\sqrt{g} = (\omega/r^3 - i\omega^2/r^2)\ \exp[i\varphi + i\omega(r-t)]/4\pi, \tag{3.4}$$

$$B^\varphi = e^{\varphi r\theta} B_{r\theta}/\sqrt{g} = (i\omega/r^3 + \omega^2/r^2)\cos\theta\ \exp[i\varphi + i\omega(r-t)]/(4\pi\sin\theta). \tag{3.5}$$

Therefore we have the time average spin tensor of the form

$$< \Upsilon^{ijk} = \underset{e}{\Upsilon}^{ijk} + \underset{m}{\Upsilon}^{ijk} >= \Re\{E^{*[i}\nabla^{|k|}E^{j]} + B^{*[i}\nabla^{|k|}B^{j]}\}/2\omega^2, \tag{3.6}$$

Covariant derivatives, for example

$$\nabla_k E^i = \partial_k E^i + \Gamma^i_{jk} E^j, \tag{3.7}$$

need connection coefficients Γ^i_{jk}:

$$\Gamma^r_{\theta\theta} = -r,\quad \Gamma^r_{\varphi\varphi} = -r\sin^2\theta,\quad \Gamma^\theta_{\varphi\varphi} = -\sin\theta\cdot\cos\theta,\quad \Gamma^\varphi_{\theta\varphi} = \cos\theta/\sin\theta,\quad \Gamma^\theta_{r\theta} = \Gamma^\varphi_{r\varphi} = 1/r \tag{3.8}$$

Using (2.6) – (2.8), (3.4) – (3.8) yields two components of the electric part of the spin tensor,

$$< \underset{e}{\Upsilon}^{\theta\varphi r} >= (\omega^3/r^4 - 2\omega/r^6)\cos\theta/(32\pi^2\sin\theta), \tag{3.9}$$

$$< \underset{e}{\Upsilon}^{\varphi rr} >= -\omega/(r^5 32\pi^2), \tag{3.10}$$

and the magnetic part

$$< \underset{m}{\Upsilon}^{\theta\varphi r} >= \omega^3\cos\theta/(r^4 32\pi^2\sin\theta). \tag{3.11}$$

So, we have two components of the spin tensor

$$< \Upsilon^{\theta\varphi r} >=< \underset{e}{\Upsilon}^{\theta\varphi r} > + < \underset{m}{\Upsilon}^{\theta\varphi r} >= (\omega^3/r^4 - \omega/r^6)\cos\theta/(16\pi^2\sin\theta), \tag{3.12}$$

$$< \Upsilon^{\varphi rr} >=< \underset{e}{\Upsilon}^{\varphi rr} >= -\omega/(r^5 32\pi^2). \tag{3.13}$$

The spin angular momentum flux relative to z-axis across an element da_i is the dualized three-vector:

$$d^3S_z/dt = d\underset{S}{\tau}_z = \hat{z}^l \Upsilon^{ijk} da_k \sqrt{g}\, e_{lij}/2 = (\hat{z}^r \Upsilon^{\theta\varphi r} + \hat{z}^\theta \Upsilon^{\varphi rr}) da_r \sqrt{g}\ . \tag{3.14}$$

as in the case with the angular momentum flux (1.5). Using (2.14) yields the time average spin flux radiated by the dipole

$$\underset{S}{\tau}_z = \int [\omega^3\cos^2\sin\theta + (\omega/2r^2)(-2\cos^2\theta\sin\theta + \sin^3\theta)]d\theta d\varphi/(16\pi^2) = \omega^3/(12\pi). \tag{3.15}$$

The second term in this integrand describes an interesting phenomenon. Except the spin flux (3.15) that is radiated to infinity, a closed spin flow circulates not far from the rotating dipole. This spin flow is directed outside in the equatorial area, but is returned back in the polar area because

$$\int (-2\cos^2\theta\cdot\sin\theta + \sin^3\theta)d\theta d\varphi = 0. \tag{3.16}$$

This is a torque strength of the electromagnetic field.

Thus the circular oscillator radiates spin flux

$$\underset{S}{\tau}_z = dS_z/dt = \int \omega^3\cos^2\sin\theta\, d\theta d\varphi/(16\pi^2) = \omega^3/(12\pi). \tag{3.17}$$

Angular distribution of this spin flux is

$$d\underset{S}{\tau}_z/d\Omega = \omega^3\cos^2\theta/(16\pi^2) \tag{3.18}$$

instead of (1.9). This is depicted in Fig. 2. Note that the ratio of the spin flux density to the power density at $\theta = 0$ equals to $1/\omega$, just as for a photon, because the radiation is circularly polarized along the direction $\theta = 0$:

$$\left.\frac{\omega^3\cos^2\theta/(16\pi^2)}{\omega^4(\cos^2\theta + 1)/(32\pi^2)}\right|_{\theta=0} = \frac{1}{\omega}. \tag{3.19}$$

However, the total spin flux (3.17) is half of the total orbital angular momentum flux (1.2), (2.15).

4. Appendix. Spin tensor

We see that the Maxwell electrodynamics provides the deficit of angular momentum in the polar regions. So, the electrodynamics is not complete. We introduce a spin tensor in the electrodynamics.

The standard classical electrodynamics starts from the free field canonical Lagrangian,

$$\underset{c}{\mathrm{L}} = -F_{\mu\nu}F^{\mu\nu}/4, \quad F_{\mu\nu} = 2\partial_{[\mu}A_{\nu]}. \tag{4.1}$$

Using this Lagrangian, by the Lagrange formalism physicists obtain the canonical energy-momentum tensor

$$\underset{c}{T}{}^{\lambda\mu} = \partial^{\lambda}A_{\alpha}\frac{\partial \underset{c}{\mathrm{L}}}{\partial(\partial_{\mu}A_{\alpha})} - g^{\lambda\mu}\underset{c}{\mathrm{L}} = -\partial^{\lambda}A_{\alpha}F^{\mu\alpha} + g^{\lambda\mu}F_{\alpha\beta}F^{\alpha\beta}/4, \tag{4.2}$$

and the canonical total angular momentum tensor

$$\underset{c}{J}{}^{\lambda\mu\nu} = 2x^{[\lambda}\underset{c}{T}{}^{\mu]\nu} + \underset{c}{\Upsilon}{}^{\lambda\mu\nu} \tag{4.3}$$

where

$$\underset{c}{\Upsilon}{}^{\lambda\mu\nu} = -2A^{[\lambda}\delta^{\mu]}_{\alpha}\frac{\partial \underset{c}{\mathrm{L}}}{\partial(\partial_{\nu}A_{\alpha})} = -2A^{[\lambda}F^{\mu]\nu}, \tag{4.4}$$

is the canonical spin tensor.

Then physicists accomplish a Belinfante-Rosenfeld procedure [12, 13]. They add specific terms to the canonical tensors and arrive to the standard energy-momentum tensor $\Theta^{\lambda\mu}$, the standard total angular momentum tensor $\underset{st}{J}{}^{\lambda\mu\nu}$, and the standard spin tensor $\underset{st}{\Upsilon}{}^{\lambda\mu\nu}$, which is zero,

$$\Theta^{\lambda\mu} = \underset{c}{T}{}^{\lambda\mu} - \partial_{\nu}\underset{c}{\tilde{\Upsilon}}{}^{\lambda\mu\nu}/2 = -\partial^{\lambda}A_{\nu}F^{\mu\nu} + g^{\lambda\mu}F_{\alpha\beta}F^{\alpha\beta}/4 + \partial_{\nu}(A^{\lambda}F^{\mu\nu}),$$

$$\underset{c}{\tilde{\Upsilon}}{}^{\lambda\mu\nu} \overset{def}{=} \underset{c}{\Upsilon}{}^{\lambda\mu\nu} - \underset{c}{\Upsilon}{}^{\mu\nu\lambda} + \underset{c}{\Upsilon}{}^{\nu\lambda\mu} = -2A^{\lambda}F^{\mu\nu}, \tag{4.5}$$

$$\underset{st}{J}{}^{\lambda\mu\nu} = \underset{c}{J}{}^{\lambda\mu\nu} - \partial_{\kappa}(x^{[\lambda}\underset{c}{\tilde{\Upsilon}}{}^{\mu]\nu\kappa}), \tag{4.6}$$

$$\underset{st}{\Upsilon}{}^{\lambda\mu\nu} = \underset{st}{J}{}^{\lambda\mu\nu} - 2x^{[\lambda}\Theta^{\mu]\nu} = \underset{c}{\Upsilon}{}^{\lambda\mu\nu} - \underset{c}{\tilde{\Upsilon}}{}^{[\lambda\mu]\nu} = 0. \tag{4.7}$$

This means that standard addends $\underset{st}{t}{}^{\lambda\mu}$, $\underset{st}{s}{}^{\lambda\mu\nu}$ are added to the canonical energy-momentum and spin tensors:

$$\Theta^{\lambda\mu} = \underset{c}{T}{}^{\lambda\mu} + \underset{st}{t}{}^{\lambda\mu}, \quad \underset{st}{t}{}^{\lambda\mu} = -\partial_{\nu}\underset{c}{\tilde{\Upsilon}}{}^{\lambda\mu\nu}/2 = \partial_{\nu}(A^{\lambda}F^{\mu\nu}), \tag{4.8}$$

$$\underset{st}{\Upsilon}{}^{\lambda\mu\nu} = \underset{c}{\Upsilon}{}^{\lambda\mu\nu} + \underset{st}{s}{}^{\lambda\mu\nu} = 0, \quad \underset{st}{s}{}^{\lambda\mu\nu} = -\underset{c}{\Upsilon}{}^{\lambda\mu\nu} = 2A^{[\lambda}F^{\mu]\nu}. \tag{4.9}$$

We use another addends; our addends,

$$t^{\lambda\mu} = \partial_{\nu}A^{\lambda}F^{\mu\nu}, \quad s^{\lambda\mu\nu} = 2A^{[\lambda}\partial^{\mu]}A^{\nu}, \tag{4.10}$$

satisfy the equation

$$2t^{[\lambda\mu]} = \partial_{\nu}s^{\lambda\mu\nu} \tag{4.11}$$

and lead to the Maxwell energy-momentum tensor

$$T^{\lambda\mu} = \underset{c}{T}{}^{\lambda\mu} + t^{\lambda\mu} = -F^{\lambda}{}_{\nu}F^{\mu\nu} + g^{\lambda\mu}F_{\alpha\beta}F^{\alpha\beta}/4 \tag{4.12}$$

and a tensor, which is doubled electric part $\underset{e}{\Upsilon}{}^{\lambda\mu\nu}$ of the electrodynamics spin tensor $\Upsilon^{\lambda\mu\nu}$,

$$2\underset{e}{\Upsilon}{}^{\lambda\mu\nu} = \underset{c}{\Upsilon}{}^{\lambda\mu\nu} + s^{\lambda\mu\nu} = 2A^{[\lambda}\partial^{|\nu|}A^{\mu]}. \tag{4.13}$$

This result was submitted to “JETP Letters” on May 12, 1998.

The expression (4.13) was obtained heuristically. It is not final one. The tensor (4.13) is obvious not symmetric in the sense of electric - magnetic symmetry. It represents only the electric field, $\mathbf{E}$, $\mathbf{A} = -\int \mathbf{E}dt$. A true spin tensor of electromagnetic waves must depend symmetrically on the magnetic vector potential A_{α} and on an electric vector potential

$$\Pi_\alpha = e_{\alpha\lambda\mu\nu}\Pi^{\lambda\mu\nu}, \quad \partial_\nu \Pi^{\lambda\mu\nu} = F^{\lambda\mu}. \tag{4.14}$$

So the spin tensor of electromagnetic waves has the form

$$\Upsilon^{\lambda\mu\nu} = \underset{e}{\Upsilon}^{\lambda\mu\nu} + \underset{m}{\Upsilon}^{\lambda\mu\nu} = A^{[\lambda}\partial^{|\nu|}A^{\mu]} + \Pi^{[\lambda}\partial^{|\nu|}\Pi^{\mu]}, \tag{4.15}$$

and the total angular momentum has the form

$$J^{\lambda\mu} = \int (2x^{[\lambda}T^{\mu]\nu} + \Upsilon^{\lambda\mu\nu})dV_\nu, \ \text{ or } \quad \mathbf{J} = \int \mathbf{r}\times(\mathbf{E}\times\mathbf{B})dV + \int \Upsilon^{ij0}dV. \tag{4.16}$$

Conclusions, Notes, and Acknowledgements

This paper conveys new physics. We review existing works concerning electrodynamics spin and indicate that existing theory is insufficient to solve spin problems because spin tensor of the modern electrodynamics is zero. Then we show how a change of the Belinfante-Rosenfeld procedure resolves the difficulty by introducing a true electrodynamics spin tensor. Our spin tensor, in particular, doubles a predicted angular momentum of a circularly polarized light beam without an azimuth phase structure and explains the Beth experiment.

Unfortunately, materials of this paper were rejected more than 350 times by scientific journals. For example (I show an approximate number of the rejections in parentheses): JETP Lett. (8), JETP (13), TMP (10), UFN (9), RPJ (70), AJP (16), EJP (4), EPL (5), PRA (4), PRD (4), PRE (2), APP (5), FP (6), PLA (9), OC (5), JPA (4), JPB (1), JMP (6), JOPA (3), JMO (2), CJP (1), OL (4), NJP (2), MPEJ (3), arXiv (70). In particular, OC rejected a paper “Inner incompleteness of the Maxwell electrodynamics” submitted on 22 Sep 2002.

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References

1. L. D. Landau, E. M. Lifshitz, *The Classical Theory of Fields* (Pergamon, N. Y. 1975).
2. A. Corney, *Atomic and Laser Spectroscopy* (Oxford University Press, 1977).
3. R. I. Khrapko www.mai.ru/projects/mai_works/articles/num3/article6/auther.htm (2001)
4. R. A. Meyers, *Encyclopedie of Physics Science and Technology*, v. 2 (N.Y., AP, 1987).
5. R. P. Feynman, R. B. Leigton, and M. Sands M, *The Feynman Lectures on Physics*, v. 3, (Addison-Wesley, London, 1965)
6. D. Sivoukhin, *Cours de physique generale. Electricite*, v. 3, (Traduction Francaise Editions, Mir, Moscow, 1983).
7. R. I. Khrapko, in *Abstracts on 10th Russian Gravitational Conference* (Moscow, 1999).
8. R. I. Khrapko, physics/0105031.
9. R. I. Khrapko, Measurement Techniques **46** No. 4, 317 (2003)
10. R. I. Khrapko, Gravitation & Cosmology, **10**, 91 (2004)
11. R. I. Khrapko mp_arc@mail.ma.utexas.edu 03-315
12. F. J. Belinfante, Physica **6,** 887 (1939).
13. L. Rosenfeld, Memoires de l'Academie Royale des Sciences de Belgiques **8** No 6 (1940).
14. R. I. Khrapko, Amer. J. Phys. **69**, 405 (2001).