This is

Review report (red) of the manuscript 175608 (JOSA B)

http://khrapkori.wmsite.ru/ftpgetfile.php?id=100&module=files

entitled: **"Angular momentum of light"**

by Radi I. Khrapko

and Khrapko's comment.

It seems that the authors intend to discuss the angular momentum of light. But the manuscript is so badly written that I'm still unable to understand what the author wants to report in the manuscript. So it is recommended that the manuscript be rejected for publication in JOSA B. I give in the following my main arguments:

No comment

1.

The manuscript is poorly organized and badly written. It's just a draft of work, far from a final paper. There are many incomplete sentences. The manuscript is composed of separated pieces without logic between them.

No comment

2.

The title is too vague, too general. We cannot know what is dealt with in the manuscript.

Angular momentum of light is discussed in the manuscript

3.

The abstract is not well written.

a.

The logic of the second sentence is not correct: he talks at the same time "momentum" and "total angular momentum" in the reason but he concludes only in "spin and moment of momentum".

No, the logic is correct: $\mathbf{J} = \mathbf{S} + \mathbf{L}$, $\mathbf{L} = \mathbf{r} \times \mathbf{P}$, so conservation of $\mathbf{P}$ and $\mathbf{J}$ entails conservation of $\mathbf{S}$ and $\mathbf{L}$: $d\mathbf{L} = d\mathbf{r} \times \mathbf{P} = md\mathbf{r} \times d\mathbf{r} / dt = 0$

b.

What means here "concrete value"? Does he want to compare with some physical quantities which are "non-concrete"?

Sorry, I have written, "spin and moment of momentum have concrete **values**". I compare my concept with the standard concept. According to the standard concept, spin **is** a moment of momentum, so spin and moment of momentum have the same concrete value.

c.

How the "two types of angular momentum" can be "spatially separated"?

Spin is in the bulk of a circularly polarized beam with plane front, and moment of momentum exists at the lateral surface of the beam

d.

What's the "supposition" to be verified? If the author proposes a supposition, it must be stated clearly.

Yes, I have stated the supposition: "These two types of angular momentum are spatially separated. Flux of spin and flux of moment of momentum act on an absorber independently".

4.

The author can cite the work of other researchers, but it must be reformulated in a coherent style. The direct copy of the original text is not encouraged, since it can be confusing in different context. The author cites too much original texts and they are not well commented, no well-organized neither.

Sorry, I state at the very beginning of the Introduction: "A torque acts on a body, which absorbs a circularly polarized light". And my comment is: "the angular momentum density j_z, which is proportional to the energy density, is the spin density s_z, $s_z = j_z$" (according to Feynman, Beth, Carrara). If Reviewer agrees, he can skip all copies; the copies only confirm the state.

5.
The title of the first section is strange: Is that the introduction of the manuscript or is it devoted to the Spin of light which is only one type the angular momentum of light the author want to talk in the manuscript.
The section, **1. Introduction. Spin of light,** is the introduction of the standard concept of light angular momentum. According to the standard concept, angular momentum of light with plane phase front is spin.
6.
The first section of a paper is often an introduction to present a state of art of the subject treated in the paper, formulae and figures are usually not necessary. The author should state clearly the position of the problem and what he wants to deal with. But the content of the first section of the manuscript is so confusing (only some citations without comments) that I do not understand what the author wants to say. The section is closed without conclusion, nor statement on the relation with what he wants to deal with.
The Introduction is not contents and is not a plan of the manuscript. The only aim of the Introduction is to recall that, according to the standard concept, a circularly polarized light with plane front acts on a body with a torque because of its spin, and the spin density is proportional to energy density
7.
At the beginning of the section 2 the author claims that "Unfortunately, now there is no conventional expression for the spin torque density μ_z. in terms of electromagnetic fields". Then he discusses the calculation of density of spin and total spin. He should know that even the spin torque is related with the spin density but they are not the same. When we talk about a torque, it means a torque exerted on an object. So the torque exerted on an object depends also on the property of it.
Yes, the torque depends on the object. But we must be able to calculate the torque in terms of electromagnetic fields around the object.
8.
The section 3 deals with "boundary of wave" but I have not understood what the author wants to show. Here I cite an example to show that the author is not rigorous: at the first line of this section: "… which sometimes can be calculated by the formulae (2.1), (2.9)…", the conditions should be stated clearly.
Sorry, I am rigorous. I have written in page 3: "The expression (2.1) is successfully used for simple plane waves. But it appears that the expression is wrong for a somewhat complicated wave. Really, consider a standing wave…"
9.
In the paragraph before Eq. (4.2), the author claims that "But they are mistaken" and the author cites only his unpublished paper. Furthermore, the text that follows is so badly written that I cannot understand his arguments.

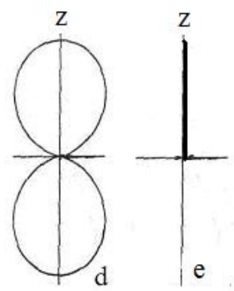
Physicists are sure that moment of momentum, $\mathbf{L}=\frac{1}{c^2}\int(\mathbf{r}\times\mathbf{S})dV$, **is** spin, $\varepsilon_0\int\mathbf{E}\times\mathbf{A}\,dV$, because spin is equal to moment of momentum

$$\varepsilon_0\int\mathbf{E}\times\mathbf{A}\,dV=\frac{1}{c^2}\int(\mathbf{r}\times\mathbf{S})dV \tag{4.1}$$

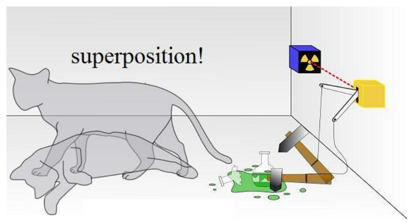
for a light beam with plane phase front. To confirm this identification, Jackson [8] and Becker [20] tried to generalize equation (4.1) to a free electromagnetic radiation produced by a source localized in a finite region of space. And they obtained the equality (4.1) as well. But they were mistaken. A straight calculation presented in **published paper** [21] for the radiation of a rotating dipole gives

$$2\varepsilon_0\int\mathbf{E}\times\mathbf{A}\,dV=\frac{1}{c^2}\int(\mathbf{r}\times\mathbf{S})dV\,. \tag{4.2}$$

As a result, equality (4.2) proves the moment of momentum is not the spin! I can insert materials of the paper into the manuscript, but such result (4.2) must be expected because when radiating into space photons are directed variously, and their spins are not parallel to each other as in a beam. Angular distribution of z-component of the spin flux for the rotating dipole radiation **(d)**, and for a beam **(e)** is depicted here.



10.
Section 5: here again, does the author want to talk about the torque or the angular momentum? (cf point 7 above).
Section 5, **Absorption of the circularly polarized beam,** talks about the torque, which exerted on an object because of absorption of the angular momentum of the circularly polarized beam.
11.
The experiment described in section 6 is a real experiment or a thought experiment? Here again, the section ended without conclusion. The author makes just two suppositions at the end of this section.
A **thought experiment** or ***Gedankenexperiment*** (from German) considers some hypothesis, theory, or principle for the purpose of thinking through its consequences. A famous example, Schrödinger's cat (1935), presents a cat that might be alive or dead, depending on an earlier random event. It illustrates the problem of the Copenhagen interpretation applied to everyday objects.



The experiment described in section 6 is a real experiment. It will show *where* the torque is exerted. The conclusion is: “If spin (2.9) exists, the fringes shift (6.5) must be equal to 2 when the inner part is rotated. If angular momentum (3.1) exists, the enormous fringes shift must be at the edge of the alight zone when the outer part is rotated”.
12.
The author gives no clear conclusion in the conclusion section. He claims that he “attempts to clarify and correct some questions in one of the 4 or so century-old controversies in classical electrodynamics, perhaps the major one of interest in modern optics”!!! But what questions and what controversies? These merit a very clear statement here if any.
Well, now Conclusion is:
Simmonds and Guttmann [16] claimed: “A classical quantity associated with the electromagnetic field does not necessarily indicate the value of that quantity which will be measured. The angular momentum density of the wave was zero at the center, yet when we attempted to measure it there the classical field adjusted themselves and produced a nonzero measurement”. We suggest an experiment to explain this magic trick.

Reviewer 2

This article seeks to clarify the nature of the angular momentum of light and suggests an experiment to measure the torque acting on an absorber.   I do not recommend the publication of this article for the following reasons
1.
It does not have a coherent thread, but rather discusses in a cursory fashion different aspects related to the angular momentum of light, reviewing articles in the literature on the subject with quotations.
The coherent thread is: According to Sadowsky, Poynting, Feynman, Beth, Carrara, et al., spin density is proportional to energy density (section 1), but there is no conventional expression for the spin density. The expression used by Ohanian, Friese, et al. is wrong (section 2). At the same time according to Heitler, Simmonds and Guttmann, et al., the spin density is proportional not to energy density but to gradient of the energy density (section 3). Contrary to this opinion, Humblet, Nieminen, Jackson, Becker, et al. consider spin, which proportional to energy, and “spin”, which proportional to gradient, as the same matter. But their reasoning contains an error (section 4). So,

the question arises: *where* are located these two type of "spin"? (section 5) The experiment can show the location (section 6).

2.

The author's contribution to the subject of optical angular momentum are obscure and unconvincing, referring to own unpublished work for example in refs. [21] and [22]

The works [6, 7, 21, 22, 24] by Khrapko are published. But I can insert materials of these works into the manuscript with pleasure.

3.

The experiment suggested is based on questionable concepts. In particular, the author says on page 7, lines 1 to 4 `If the plate rotates in its own plane, work will be done. This (positive or negative) amount of work must reappear as an alteration in the energy of the photons, i.e. in the frequency of the light, which will result in moving interference fringes in any suitable interference experiment.' This is conceptually wrong. If light does work, it simply exchanges energy by processes of absorption or emission of whole photons without changes in frequency (i.e. quantum of energy carried by one photon is intact). In my opinion the premise on which this suggested experiment is based is totally wrong.

This conclusion discredits the Reviewer 2 completely. R. Atkinson [27] wrote about the Righi's experiment: "the experiment is shortly described in Wood's *Physical Optics*. Righi's arrangement may be somewhat simplified, so that the effect can be observed with an ordinary student's optical bench and Fresnel biprism".

Reviewer 3

This paper attempts to clarify the following question: Does plane wave not carry a spin?
It proposes an original version of an experiment already proposed by the author some years ago (Ref. 24). The major critical point of this paper is that it does not correctly cite the existing literature on the argument that was already debated some years ago. In particular ref. 24 received a very good answer by V. B. Yurchenko (Am. J. Phys. 70, 568 (2002).

In reality, Ref. 24 received two bad answers (Am. J. Phys. **70**, 567, 568): by L. Allen, M. J. Padgett, and by V. B. Yurchenko. Unfortunately, Jan Tobochnik, AJP Editor, rejected my comments on the answers (manuscript #15916). He wrote on 19 Jun 2002, "I believe that this paper should not be published. I think it attempts to raise issues with, and modify, the standard formulation of electrodynamics that already does an adequate job of describing physical systems". Luckily, Prof. **Jonathan Marangos,** Editor Journal of Modern Optics, published my comments on Allen & Padgett's answer [25]. I wrote in [6]:

> Allen and Padgett [25] try to explain the action of a circularly polarized plane wave by a torque on a central region of an absorbing plane in the frame of the standard paradigm. They cut the wave into coaxial pieces in their mind and then claim that every piece produces a torque because the large intensity gradient near the boundary of the piece results in azimuthal components to the momentum density.
>
> I think this is not correct. An intensity gradient near a wall of a beam results in the azimuthal components only in the case of a real beam satisfying the Maxwell equations. There are no azimuthal components in a piece of a wave that is simply cut off from a whole wave. Such a piece cannot be considered at all because it does not satisfy the Maxwell equations.

Unfortunately, there is no answer on this criticism during four years.

I comment Allen & Padgett's answer [25] in the present manuscript as well. But I ignored Yurchenko's answer because Yurchenko [27] gave no answer, does or does not an inner part of the absorber perceive a torque in a circularly polarized light? And his trivial conversation about "performing an integration by parts, which **moves** the nonzero values of the density of **J** from the border to the bulk of the beam" is discussed in section 4 in details. Nevertheless I greet

Yurchenko's proof "that angular momentum is carried by an infinite uniform circularly polarized plane wave", and now I cite Yurchenko's answer in the revised version of the manuscript.
#
The paper by Yurchenko [27] must be absolutely cited. In particular in the introduction of Khrapko's paper the following sentence from the Yurchenko's answer must be inserted "A rigorous answer (to the question Does plane wave not carry a spin) is provided by quantum mechanics so that the question is a matter of an adequate quasiclassical approximation. A useful discussion of the angular momentum using a quasiclassical approximation is given by Simmons and Guttmann". And the book by Simmons and Guttmann [16] must be cited with the pages where this argument is treated.
Sorry, I used the option "*find* quasiclassical". The answer was: "Reader has finished searching the document. No matches were found"
#
Finally the paper by Allen et al PRA 45, 8185 (1992) on orbital angular momentum and LG laser modes must be cited as well.
No, the paper by Allen et al. is devoted to Laguerre-Gaussian modes, which have an azimuthal angular dependence. I discuss this topic in details in another place: http://www.mai.ru/science/trudy/articles/num27/article10/auther.htm (in Russian), "Inevitability of the electrodynamics' spin tensor" http://khrapkori.wmsite.ru/ftpgetfile.php?id=29&module=files (A series of theoretical and experimental works confirms reality of the spin tensor. Rejected by all scientific journals).
#
These are considered as major revisions because it is not possible to continue to insist on an argument without even considering the answers that were received previously.
Oh! Yes! Please summon L. Allen and M. J. Padgett to answer on my criticism!

References

[1] Sadowsky A. *Acta et Comm. Imp. Universitatis Jurievensis* 7, No. 1-3 (1899)
[2] Poynting J. H., The wave motion of a revolving shaft, and a suggestion as to the angular momentum in a beam of circularly polarised light. *Proc. R. Soc. Lond.* A 82, 560-567.
[3] Feynman R. P., R. B. Leighton, M. Sands, The Feynman Lectures on Physics (Addison–Wesley, London, 1965) Vol. 3, 17–4.
[4] Beth R. A., "Mechanical detection and measurement of the angular momentum of light" *Phys. Rev*. 50, 115 (1936).
[5] Carrara, N. Torque and Angular Momentum of Centimetre Electromagnetic Waves. *Nature* 164 (1949) 882.
[6] Khrapko R. I., "Mechanical stresses produced by a light beam," *J. Modern Optics* 55, 1487-1500 (2008)
[7] Khrapko R. I., Experiment Concerning Electrodynamics' Nonlocality http://www.mai.ru/science/trudy/published.php?ID=28833 (2012). See also http://khrapkori.wmsite.ru/ftpgetfile.php?id=46&module=files
[8] Jackson J. D., Classical Electrodynamics, (John Wiley, 1999), p. 350.
[9] Ohanian H. C., "What is spin?" *Amer. J. Phys*. 54, 500-505 (1986).
[10] M. E. J. Friese, T. A. Nieminen, N. R. Heckenberg & H. Rubinsztein-Dunlop, *Nature* 394, 348–350 (1998)
[11] J. H. Crichton and P. L. Marston, "The Measurable Distinction Between the Spin and Orbital Angular Momenta of Electromagnetic Radiation" *Electronic Journal of Differential Equations Conf.* 04, 37 (2000).
[12] F. Rohrlich, *Classical Charged Particles*, (Addison-Wesley, Mass. 1965)
[13] Heitler W., The Quantum Theory of Radiation (Oxford: Clarendon, 1954) p. 401
[14] Allen, L.; Padgett, M.J.; Babiker, M. The orbital angular momentum of light. *Progress in Optics XXXIX*; Elsevier: Amsterdam, 1999, p 299.

[15] Zambrini, R.; Barnett, S.M. Local transfer of optical angular momentum to matter. *J. Mod. Opt*. 52: (2005) 1045–1052.
[16] Simmonds J. W., M. J. Guttmann, States, Waves and Photons (Addison-Wesley, Reading, MA, 1970)
[17] Humblet J., "Sur le moment d'impulsion d'une onde electromagnetique". *Physica (Utrecht)* **10** Issue 7, p.585-603 (1943)
[18] Crichton J., T. Medina, Spin matrices for gravitons and the humblet decomposition of the angular momentum of gravitational radiation in the linearized theory, *Gen. Relat. Grav*., 22, 61 (1990)
[19] Nieminen T. A., Theodor Asavei, Vincent L.Y. Loke, Norman R. Heckenberg, Halina Rubinsztein-Dunlop, "Symmetry and the generation and measurement of optical torque" *Journal of Quantitative Spectroscopy and Radiative Transfer*, Volume 110, Issues 14–16, September–November 2009, Pages 1472-1482
[20] Becker R., Electromagnetic Fields and Interactions, V. 2, (NY, Dover, 1964), p.320.
[21] Khrapko R. I., Spin is not a moment of momentum http://www.mai.ru/science/trudy/published.php?ID=28834 (2012). See also http://khrapkori.wmsite.ru/ftpgetfile.php?id=76&module=files
[22] Khrapko R. I.. "Radiation of spin by a rotator," http://www.ma.utexas.edu/cgi-bin/mps?key=03-315 (2003)
[23] Meyers, R. A. Encyclopedie of Physics Science and Technology, v. 2 (N.Y., AP, 1987).
[24] Khrapko R. I., "Does plane wave not carry a spin?" *Amer. J. Phys*. 69, 405 (2001).
[25] L. Allen, M. J. Padgett, "Response to Question #79. Does a plane wave carry spin angular momentum?" *Am. J. Phys*. 70, 567 (2002)
[26] Atkinson R. d'E., "Energy and Angular Momentum in Certain Optical Problems", *Phys. Rev*. 47, 623-627 (1935).
[27] V. B. Yurchenko. "Answer to Question #79. Does plane wave not carry a spin?" *Am. J. Phys*. 70, 568 (2002)