Manuscript: Spin is not a moment of momentum (AJP-24278, revised version)
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REFEREE'S REPORT

In this revised version of his manuscript, the author has responded in part to my previous comments by supplying some further background information. However, I do not think he has taken serious account of the educational purpose that articles published in AJP are expected to serve, namely that they should be accessible to, and engage the interest of, students of physics in their undergraduate or early graduate years of study. The style of writing that achieves this purpose is, I think, quite well exemplified by the Ohanian article cited by the author as Ref. 12. This article begins with an introduction, setting out the issues to be discussed in terms that can be understood, at least in outline, with a minimum of specialist knowledge, while the later, more technical material is phrased in straightforward language that should be broadly familiar to an advanced undergraduate, and present very little difficulty to a graduate student who has some grounding in relativistic quantum mechanics. By contrast, the present manuscript has no introductory section, from which a reader might gain some preliminary sense of the direction in which the discussion is heading, and the writing is so terse that a very close reading is needed, even on the part of an experienced physicist, to gain a clear sense of what the author wishes to say.

Regarding the content of the manuscript, I am afraid the author has misinterpreted some of my previous comments as a "request for an unambiguous definition of momentum density". What I intended to ask for (and I thought I had done so clearly) is a recognition on the author's part that no unique definition of momentum density in the electromagnetic field is possible. In effect, he now seeks to demonstrate that there is such a unique definition by asserting that the electromagnetic field is merely an example of a continuous mechanical medium. But that is manifestly untrue. It makes good sense, for example, to speak of the displacement of an element of an elastic body in response to a force acting on its surface, as in the discussion surrounding equation (1.3), but one cannot speak in the same way of a displacement of an element of an electric field, or of a force acting on its surface. For an elastic medium or a fluid, momentum density, spin density and so on can be unambiguously defined by summing the corresponding properties of its constituent particles, and the ambiguity in the definition of these densities for the electromagnetic field could be understood as arising from the fact that this field has no constituent particles. As I indicated in previous comments, the ambiguity is alleviated in a quantum-mechanical treatment, where one can indeed identify momentum and spin densities as those associated with an assemblage of photons. This is an important aspect of the problem which the author completely ignores. Up to a residual ambiguity in a choice of gauge, the resulting separation of angular momentum into orbital and spin components is the one quoted in (4.2) - a result to which the author seems to take exception.

The author's claim (following equation (1.3) and again following (1.7)) that the identi-

fication of the energy-momentum tensor is settled unambiguously by experiment is also mistaken: there is no way of directly measuring the momentum density or spin density in an electromagnetic field. The antenna of a radio receiver responds in an unambiguous manner to the electromagnetic fields in its vicinity, but that has no direct bearing on how a momentum density should be identified in terms of these fields. Similarly, it is possible to measure experimentally the changes in momentum and angular momentum of a mechanical system that result from its interaction with an electromagnetic field, and hence to infer the *total* amount of these quantities carried by the field. But this serves only to confirm that the *total* momentum and angular momentum carried by a field configuration is unambiguously determined, and does not bear directly on the question of how densities of these quantities can be constructed from the fields themselves.

It seems to me, then, that in addition to being difficult to read, the manuscript is seriously misleading in several important respects. Certainly, the recurrent implication that many competent physicists who have studied these issues over the years are collectively guilty of some gross error is not substantiated by the arguments that the author adduces. As I have indicated previously, I think that a well-written, carefully argued article on this topic would be valuable, but I am sorry to say that I do not now believe that any straightforward modification of the present manuscript would be satisfactory.