Remarks on D. V. Skobel'tsyn's paper, "Paradoxes of the quantum theory of the Vavilov-Cerenkov and Doppler effects"

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Consider a stationary medium free of dispersion in which a source emits a sufficiently narrow and long train of electromagnetic waves characterized by the "carrier" wave vector $\mathbf{k}$ [$k = (\omega/c)n$, where ω is the carrier frequency and n the refractive index]. Suppose further that the changes in the energy and momentum of the source due to the emission of this wave train are $-\mathscr{E}$ and $-\mathbf{G}$. It is clear that the electromagnetic field and the medium, taken together, receive energy $\mathscr{E}$ and momentum $\mathbf{G}$. If we suppose that the momentum-energy tensor of the field in the medium is given by the Minkowski tensor, it is readily seen (see, for example, Ginzburg[2]) that $\mathbf{G} = \mathbf{G}^{\mathrm{M}} = \mathscr{E}(n/c)\mathbf{k}/k$. If, on the other hand, we use the Abraham tensor, the field receives the momentum $\mathbf{G}^{\mathrm{A}} = (\mathscr{E}/nc)\mathbf{k}/k$, but, at the same time, the medium experiences the Abraham force of density $\mathbf{f}^{\mathrm{A}}$ and the resultant impulse acting on the medium is

$$\mathbf{F}^{\mathrm{A}} = \int \mathbf{f}^{\mathrm{A}}\, dt\, dV = \mathbf{G}^{\mathrm{M}} - \mathbf{G}^{\mathrm{A}} = \left(\frac{n^2-1}{nc}\right)\frac{\mathscr{E}\mathbf{k}}{k}.$$

It follows that

$$\mathbf{G} = \mathbf{G}^{\mathrm{M}} = \mathbf{G}^{\mathrm{A}} + \mathbf{F}^{\mathrm{A}} \qquad (1)$$

and, therefore, the Minkowski and Abraham tensors lead to the same result when the momentum $\mathbf{G}$ is evaluated (see Ginzburg and Ugarov[3] for further details).

However, D. V. Skobel'tsyn[1] agrees with Eq. (1), which is designated by Eq. (1.6) in his paper, only for a source that is at rest in the medium. However, the given wave train cannot "know" or "remember" which particular source has emitted it, and the basic equations of macroscopic electrodynamics are valid in the stationary medium for either stationary or moving sources. In my opinion, therefore, the objections to (1) in the case of a moving source are invalid and are based on the comparison of quite different wave trains. In view of this, I see no justification for the critique of the paper by Ginzburg and Ugarov,[3] given by Skobel'tsyn.[1] 1) I should also like to emphasize that the question of the dynamics of the medium in which a wave train is propagating is much more complicated than the determination of the integrated quantities $\mathscr{E}$ and $\mathbf{G}$, and does not have a universal solution (see the last section of the paper by Ginzburg and Ugarov[3] and the papers[4,5] cited therein).

In addition, Skobel'tsyn[1] has criticized the quantum electrodynamics of a medium as expounded in a number of publications (see Ginzburg[2,6] and the references therein). For lack of space, I merely note here that I do not regard this critique to be justified. Moreover, many of the objections raised by Skobel'tsyn are totally unrelated to quantum theory.

Consider, for example, a charge in a moving medium but at rest in the laboratory reference frame. When the Vavilov–Cerenkov radiation is emitted, the charge obviously does not transfer energy to the field but, on the contrary, receives energy during the emission process; nothing else can happen since, by hypothesis, the charge is stationary (or was stationary at the beginning of the process) so that it cannot give up any energy. The growth in the vibrations of an oscillator due to the emission of waves within the Cerenkov cone, i.e., during the anomalous Doppler effect, is also classical (see, for example, Ginzburg,[6] §7, and Nezlin[7]). It is precisely these effects, when they are described in quantum language, that Skobel'tsyn[1] regards as paradoxical or connected with arbitrary assumptions.

1) I take this opportunity to note that a printing error has crept into Eq. (39) in our previous paper[3] (instead of $g_{m,\alpha}$, read g^{M}). What is more important—Eq. (44) in that paper should be replaced by

$$\mathbf{G}^{\mathrm{A}} + \int \mathbf{f}_m^{(t)}\, dt\, dV = \mathbf{G}^{\mathrm{A}} + \int \mathbf{f}^{\mathrm{A}}\, dt\, dV = \mathbf{G}^{\mathrm{M}},$$

where $\mathbf{f}_m^{(t)}$ is the force density [see, for example, Eq. (5) in that paper].

1 D. V. Skobel'tsyn, this issue, p. 528.
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