Sound beyond the speed of light: destructive interference, anomalous dispersion and nonlocality of near field

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(Dated: February 1, 2008)

Abstract

Experimentally fixed sound pulse beyond of light speed in the region of anomalous dispersion [W. M. Robertson, et al. Appl. Phys. Lett, 90, 014102 (2007)] can be explained, as well as the similar superluminal phenomena, by “the nonlocality in the small” of near electromagnetic field at transferring of relevanted excitations.

PACS numbers: 43.35+d, 03.65.Ta, 12.20.-m, 42.50.-p

Key words: superluminal, near field, anomalous dispersion, nonlocality

In last years numerous experiments (e.g., the reviews [1]) had been shown that the electromagnetic excitation or signal can be passed in substance with a speed surpassed the light speed in vacuum. The most contra-intuitive experiment [2], as if at the special contradiction to the common sense, has shown, that the speed faster-than-c is possible even for a sound in the region of anomalous dispersion in substances of normal density. (It is necessary to emphasize, that the majority of experiences of so named superluminal phenomena also were carried out in the regions of anomalous dispersion.)

Basic distinction between [2] and experiments in optical area or in electronic devices consists in the following: if the excess of speed in them was not so great and it yet was possible to think of rearrangement of waves’ envelope and so on, the speed excess in acoustics is of the six orders (!) and consequently it become evident that a more radical approach is required. Hence the adequate approach that can simultaneously explain both optical and acoustic experiments must be developed and verified, especially since it can be assumed that in the processes of superfast transferring of sound the electromagnetic phenomena can take part or even play a basic role.

It can be assumed that common complexities at consideration of these problems are connected with the examinations of solutions of the wave equations in the beforehand sup-
posed form \( f(\mathbf{v}t - \mathbf{r}) \), i.e. as the traveling waves only, that, certainly, demands performance of the condition \( v \leq c \). In a near field, however, can exist also faster decreasing non-local solutions (e.g. \( [3] \)). Therefore other approaches, without a priori introduced restrictions in the analysis of wave equations and/or of initial conditions, must be examined.

In the cited experiments of the Robertson group \([2]\), anomalous dispersion is created by destructive interference when the path length \( \Delta L \) between the long and short arms of sound circuit differs by an odd number of one-half wavelengths. (In early researches in this area the article \([4]\) must be noted, but with more complex substance that complicates precise conclusions.)

Let’s consider some details of the experiment. Oscillations’ velocity of particles in sound field \( v = p/\rho s \), where \( p \) is the acoustic pressure, \( \rho \) is the density of substance, \( s \) is the speed of sound. With stopping of atoms participating in sound process by destructive interference, each of them would emit the electromagnetic momentum \( mv = \hbar k \) in the direction of sound pulse, that at the real photon emission may correspond to the energy \( E = \hbar ck = \hbar \omega \).

But the energy, emitted at considered stopping, \( E_1 = \hbar^2 k^2/2m \), does not correspond to the momentum of real photon. Therefore the forward transferring of this momentum can go only as the tunneling. The deficit of energy

\[
\Delta E = \hbar ck - (\hbar k)^2/2m = \hbar \omega \left( 1 - \hbar \omega/2mc^2 \right)
\]

is equal to the height of potential barrier that must be overcoming by virtual photon till its possible absorption by subsequent atom on a distance \( \Delta L \). This distance coincides in accordance with the uncertainty principle with \( \hbar c/\Delta E \), i.e. with corresponding wave length.

How this process can be represented in the frame of QED? The propagator of near field can be defined via the decomposition of general propagator of quantum electrodynamics onto far, intermediate and near fields \([3]\):

\[
D_{NF}(t, \mathbf{r}) = \frac{1}{4\pi r^3} \left[ \frac{\theta(t^2 - r^2)}{r} + \frac{t\theta(r^2 - t^2)}{r} \right]
\]

(2)

(Here and below \( \hbar = c = 1 \), projectors of polarization are omitted). The propagator contains local and nonlocal parts, and its complete Fourier transform shows that just the nonlocal part corresponds to the region of anomalous dispersion:

\[
D_{NF}(\omega, \mathbf{k}) = \frac{1}{8\pi^2 \omega^2 k} \left[ \omega \theta(\omega^2 - k^2) + k\theta(k^2 - \omega^2) \right]
\]

(3)

Let’s consider this part in the \((\omega, \mathbf{r})\)-representation:
\[ D_{NF}(\omega, r) = \frac{\pi}{i \omega^2} \delta(r) - \frac{1}{2\pi i \omega^2 r^3} [\sin \omega r - \omega r \cos \omega r] \] (4)

The first term in (4) is related to the contact interaction and in our analysis must be omitted. The second term is reducing at \( \omega r \to 0 \) to

\[ D_{NF}(\omega, r) \propto \frac{\omega}{6\pi} \] (5)

and remains approximately constant till \( \omega r \sim \pi/2 \) whereupon appreciably and sufficiently promptly decreases. It means a non-local transmission of excitations on definite distances only.

The nonlocality of transfer of excitation, shown in such qualitative description, can be investigated by the deeper and the most general methods of dispersion relations based on the general requirements of causality, spectrality and so on (e.g. [5]). It does not require dynamical considerations and leads to the restriction by only the kinematical arguments.

So, in the article [6] (more detailed in [5]) we had investigated this problem in the frame of general covariant dispersion relations. But for all that, what type of excitation (electromagnetic, sound or gravitational) can be non-locally transferred and its possible speed were not predetermined: the proved theorem is of general character. It had been shown that in the region of anomalous dispersion an instantaneous transferring (instant jumps) of excitations is possible only within scopes of near field on the distances \( \Delta L \) determined by wavelength corresponding to the energy deficiency \( \Delta E \) relative to the nearest stable (resonance) state:

\[ \Delta L = \frac{\pi c \hbar}{\Delta E}(2n - 1); \quad n = 1, 2, 3, \ldots . \] (6)

This expression completely corresponds to the results of experiments [2] and allows to state that in considered experiments really was observed the instantaneous transferring of sound excitation onto strongly definite distances by near electromagnetic field.

Such conclusion seems, at first sight, excessively courageous, especially with the basic attracting of arguments, initially developed for electromagnetic theory, to acoustics. However, such reasons can be considered. Firstly, in the basis of all sound phenomena are electromagnetic interactions of particles of substance; moreover we can think that the interactions between constituents of condensed media can take place in the anomalous dispersion fields and probably can be instantaneous [7]. Second, the results of some well known "superluminal" experiments [8] can be explained by the existence of conditions of anomalous dispersion aroused by destructive interference of rays passing through
multi-layer interference filters.

So, the considered phenomenon represents quantum tunneling or "the nonlocality in the small" and is connected to particles (waves) with excess of momentum relative to energy. Notice that even at $n = 1$ the value of (6) is twice bigger the uncertainties value and therefore is measurable. If measurements of duration of a signal passage are made on distances sufficiently bigger $\Delta L$, i.e. they include both the distance of instant jump of excitation and distances with the normal speed of propagation, then, certainly, any values of signal speeds, including superluminal ones, can be received.

Notice that the considered emission of suddenly stopped atoms can be examined as the atomic bremsstrahlung (cf. [9]). It is known that just in processes of bremsstrahlung was discovered the phenomenon of gradual formation (dressing) of photons, i.e. the necessity of certain time (path) for their completion, till which they remain virtual ones [10]. This phenomenon is actively investigating in the high energy physics (e.g. [11]), but must be appreciable at very low energies also, at description of van der Waals interactions also [7]. Note that this result can be especially interesting for astrophysics and cosmology (e.g. [12] and references therein), but they are far from the purpose of this letter.

In conclusion it is possible to maintain that the analysis of experimental researches shows the nonlocality of interactions in near fields under certain conditions and on strictly definite distances only. Such conclusion does not contradict the basis of relativity considering far fields and examined only in them. We stress that our description corresponds to Wigner’s formulation of common causality: *The scattered wave cannot escape a scatterer before the initial wave reaches it.* [13].

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