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SELF-FOCUSING AND FOCUSING OF ULTRASOUND AND HYPERSOUND

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Recently new sources of intense ultrasonic and hypersonic waves have become available; these are powerful laser beams, which produce in a medium a flux of volume waves that cause induced Mandel'shtam-Brillouin scattering.

We point out in this article the possibility of self-focusing and focusing of hypersonic rays from these or other sources, and estimate the conditions for the appearance and possible consequences of these effects.

The effects under consideration are based on nonlinear processes that produce a differential in the properties of the medium inside and outside the sound ray. In particular, the effects of self-focusing of sound recall the nonlinear effects of self-focusing on electromagnetic rays in media [1-6].

1. Focusing of Sound Ray by the "Wake" of a Light Ray

A light ray may modify the properties of the medium enough to change the propagation o a sound wave. For example, absorption of light and heating of the medium change the velocit and the propagation of sound in those portions of the medium through which the light has passed (the so-called "wake" of the light ray). In dense media (liquids, solids) the speed of sound usually decreases when energy is released in the medium: $dc_s/dT < 0$, so that the thermal wake of the ray or of part of the ray with increased intensity (light filament) can serve as a sound conductor, reflecting sound on the boundary of the wake.

If the glancing angle φ between the direction of incidence and the layer of discontinuity on the boundary of the heated region is such that $\cos\varphi > c_{s.inside}/c_{s.outside}$, i.e., for small values of $\varphi < \sqrt{-\Delta c_s/c_s}$, then total internal reflection of the sound will occur and the light wake will serve as an acoustic waveguide. Usually $\Delta c_s/\Delta T \sim -k \times 10^2$ cm sec^{-1}de where k is of the order of several times unity. For example, for $\Delta T \sim 0.1°$ and $c_s \simeq 10^5$ cm/sec we obtain

$$\varphi_{cr} \simeq 10\sqrt{k\Delta T/c_s} \sim 3 \times 10^{-2};$$

the reflection of sound waves on the boundary or within the discontinuity layer can cause focusing of the sound waves inside the wake, the distance between the focal points being $L_f \sim a/\varphi$, where a is the radius of the wake.

The temperature channel has a lifetime $t \sim a^2/\kappa$, where κ is the thermal conductivity of the medium. For example, for $\kappa \simeq 10^{-2}$ cm^2/sec we obtain $t > 10^{-2}$ sec even when $a > 10^{-2}$; during that time the sound can cover a sufficiently large distance, $L \sim c_s t \sim 10$ meters, i.e., the sound "remembers" the transmitted light for a sufficiently long time.

Heating of the medium in the path of the light ray can be regulated over a wide range by selecting or adding substances which noticeably absorb the light.

2. Self-focusing of a Sound Ray

The sound ray itself may produce, at high intensities, a noticeable differential in the acoustic properties of the medium inside and outside the ray, thus ensuring self-focusing of the sound ray. For example, heating of the medium in the path of the sound ray, or a change in the average vapor tension of the medium, etc. - all can cause additional focusing and self-focusing of the sound ray by the resultant differential in the properties. For example, the heat rise is $\Delta T \sim \alpha_s I_s t/\rho C$, where C is the specific heat of the medium, I_s the sound radiation flux density, α_s the linear coefficient of sound-wave absorption, and t the time from the start of heat release. Thus, the sound wave is additionally focused by its own moving frontal part. The large sound flux densities obtainable from laser beams, $I_s \simeq (\Delta p)^2/\rho c_s \sim (\epsilon'_\rho E^2/4\pi)^2/\rho c_s$, which are of the order of hundreds of kW/cm^2 at a light-wave field $E \sim 3 \times 10^7$ V/cm, make the effects noticeable even at small values of α_s.

The condition for the self-focusing threshold will be satisfied at $\varphi_{diff} \simeq \lambda_s/a \simeq [-\Delta c_s(t)/c_s]^{\frac{1}{2}}$. At large $|\Delta c_s|$, collapse of the beam can occur, accompanied by a sharp increase in the concentration of energy, amplitudes, and pressure gradients.

Other possible effects are focusing of the sound by nonstationary expansion waves from the lateral surface of the ray, producing a tubular zone of reduced temperature (relative to the center of the beam) which reflects the diverging subrays back into the ray, in analogy with the recently considered nonstationary self-focusing of a light ray by rarefaction waves [7].

Effects of self-focusing and focusing of sound waves can be of interest in connection with the problem of destruction of solids in the focal regions, formation of cavitation in liquids, production of large concentrations of hypersonic and ultrasonic radiation, transport and directional transfer of their energy, etc.

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SPATIAL AND TEMPORAL CORRELATIONS OF ELECTRIC FIELDS IN A WEAKLY TURBULENT PLASMA

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Experimental investigations of processes of transition of a plasma into a turbulent state and of stationary turbulence are of interest to plasma physics and to various applications. These processes can be investigated by using as an example the simplest and most prevalent two-stream instability.

The most important characteristic of the turbulent state is the spectral energy density E_k^2 of the electric field.

The purpose of the present work was to determine this density by measuring the spatial autocorrelation functions of the electric fields of high-frequency oscillations excited in a plasma-beam discharge.

As is well known, development of two-stream instability is accompanied by strong heating of the plasma electrons and ions and by acceleration of an appreciable number of electrons to energies greatly exceeding the energy of the beam electrons. Apparently, the stochastic-acceleration mechanism is in operation [1-3] under these conditions. To check on this assumption it is necessary to determine the degree of stochasticity of the oscillations, and to measure the length and time of correlation of the electric fields, which determine to a considerable degree the effectiveness of the stochastic acceleration. Measurements of this type make it possible to establish the extent to which the "random phase" approximation [4], used in contemporary nonlinear theories of waveguide and oscillatory properties of plasma, is applicable under the experimental conditions. We have therefore also measured the correlation times of the electric fields and the temporal autocorrelation function.

The experiment was carried out with an electron beam with energy up to 5 keV and current 20 - 100 mA, in a magnetic field up to 2,000 G and at 10^{-4} mm Hg pressure. Under these conditions, a plasma is produced with density up to 6×10^{11} el/cm^2. With the aid of a cylindrical cavity placed ahead of the interaction chamber, the beam could be modulated at a frequency of 3,000 MHz (Fig. 1).

The spatial autocorrelation function $R(\ell)$ was determined by summing oscillations (600