SESSION OF DIVISION OF GENERAL PHYSICS AND ASTRONOMY, USSR ACADEMY OF SCIENCES (28-29 January, 1970)

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A science session of the Division of General Physics and Astronomy was held on 28 and 29 January 1970 in the Conference Hall of the P. N. Lebedev Physics Institute. The following papers and communications were heard:

1. E. R. Mustel', Physical Properties of E shells Ejected from Novas, and Comparison of these Shells with those Ejected from Supernovas.
2. V. N. Tsytovich, Elementary Excitation and the Physics of Stochastic Processes in a Plasma.
3. Yu. N. Denisyuk and V. I. Sukhanov, Hologram Recorded in a Three-dimensional Medium as the Most Perfect Image Form.
4. E. S. Voronin. Nonlinear Transformation of Images and Infrared Holography.
5. K. S. Mustafin and V. A. Seleznev. Methods of Increasing the Sensitivity of Holographic Interferrometry.

We publish here brief summaries of some of the papers and communications.

V. N. Tsytovich. Elementary Excitations and Physics of Stochastic Processes in a Plasma.

Plasma physics, to a greater degree than the physics of condensed media, is the physics of the interaction of the elementary excitations of the plasma or plasmons. This is connected with the smallness of the parameter $\epsilon = 1/N_D$, where $N_D = (4\pi/3)nd^3$ is the number of particles in a sphere having the Debye radius (n is the plasma density, $d - V_{Te}/\omega_p$ the Debye radius, V_{Te} the average thermal velocity of the electrons, and ω_p the plasma frequency). N_D usually ranges from 10^4 to 10^8 for a laboratory plasma, up to 10^8–10^{11} in cosmic plasma (10^{26} for the plasma near pulsars). The parameter ϵ characterizes the ratio of the plasmon energy to the average particle energy under conditions of thermal equilibrium. On the other hand, $\epsilon^{2/3}$ is the ratio of the potential energy of particle interaction to the kinetic energy, i.e., it characterizes the rate of the relaxation processes due to pair collisions. Even small deviations ($\sim\epsilon$) of the particle distributions from equilibrium lead to the maser effect for plasmons (instability). The plasmon energy W can increase in the limit by a very large number of times, $\sim N_D$. Even when the energy of the plasmons increases by 40–50 times, all the relaxation processes are due to the interaction between the particles and the plasmons. Therefore the plasma is most abundant under conditions when $40/W_D \ll W/nT \ll 1$ and all the relaxation processes are controlled by elementary excitations. It is frequently called turbulent. The distribution of the energy of the elementary excitations with respect to the moduli of the wave numbers $k\,(\int_0^\infty N_k dk)$ characterizes the turbulence spectrum. Just as in liquids, this spectrum is governed by nonlinear processes that alter also the scales 1/k of the pulsations. The results of investigations for Langmuir plasmons are summarized in Fig. 1. The spectra in the asymptotic region have the Kolmogorov form $1/k_0$ in different regions in which different nonlinear processes predominate. The analytically obtained asymptotic spectra are in good agreement with the results of a numerical solution of the nonlinear equations, and agree qualitatively with experiment.

A major difference between the elementary excitations considered here and those in a condensed medium lies in the character of the non-uniqueness of the dependence of the energy ω on the momentum k of the elementary excitation.

Whereas in condensed media this non-uniqueness is due to damping of the excitations, in a turbulent plasma it is due to nonlinear processes. This non-uniqueness can be described with the aid of correlation functions of random fields, which are now being measured in a majority of plasma experiments. If the field in the plasma is resolved into regular and stochastic components, $E = E^R + E^S$, $\langle E^S \rangle = 0$, then the correlation function is

$$I_{\mathbf{k},\omega} = \int \langle E(\mathbf{r}_1, t_1) E(\mathbf{r}_2, t_2)\rangle \exp[i\mathbf{k}(\mathbf{r}_1-\mathbf{r}_2) - i\omega(t_1-t_2)]\, d(\mathbf{r}_1-\mathbf{r}_2)\, d(t_1-t_2).$$

The integral $\int I_{\mathbf{k},\omega} d\omega$ is proportional to $W_\mathbf{k}$, which describes the turbulence spectrum. A general theory of correlation function has been constructed by summing the series with respect to the turbulence energy near resonance ($|\omega - \omega(k)| \ll \omega(k)$) and it has been shown that the correlations are described by the Lorentz formula

$$I_{\mathbf{k},\omega} = \frac{C(k)}{[\omega - \omega^N(k)]^2 + (\gamma_k^N)^2},$$

where $\omega^N(k)$ takes into account the nonlinear frequency shift, that depends on the turbulence energy W, and $\gamma_\mathbf{k}^N$ is the nonlinear decrement. For each $W_\mathbf{k}$ on the turbulence spectrum it is possible to construct a corresponding correlation curve, as illustrated in Fig. 2 for Langmuir excitations. The formalism developed makes it possible to reduce the results of many measurements of correlation effects in a plasma by determining from the correlation effects the turbulence energy and other plasma parameters. It has been shown that $\gamma_\mathbf{k}^N$ can be lower than the collision frequency

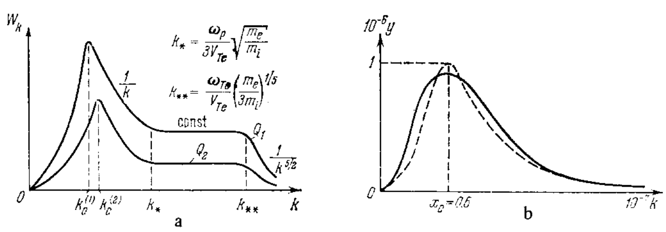

FIG. 1

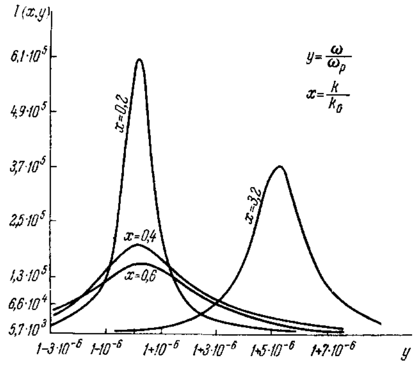

FIG. 2

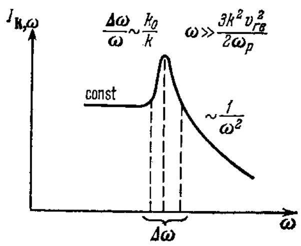

FIG. 3

and the linear increments, owing to their cancellation by the nonlinear processes under conditions of stationary turbulence. Far from the resonance $\omega = \omega(k)$ (on the "tails") there arise oscillations in which there is no unique relation between ω and k. Their spectrum can be obtained if one knows the turbulence spectrum (Fig. 3). It is interesting that the maximum frequency of these oscillations is equal to the difference between the frequencies of the high-frequency excitations. Exactly such an effect was observed experimentally by exciting stochastic oscillations under conditions of plasma-beam interaction (Ya. B. Fainberg). These low-frequency pulsations lead to stochastic heating of the particles. If the particle distribution function is resolved in regular and stochastic components, $f = f^R + f^S$, then the equation for f^R described diffusion in momentum space, and the diffusion on the "tail" of the correlation curve, which is proportional to $I_{k,\omega}$, has the same order as the $I^2_{k,\omega}$ effects, and their sum describes exactly the induced scattering of plasmons with allowance for two scattering processes—scattering by the main charge and by its surrounding "jacket" of charges of opposite sign. The presence of such a "jacket" alters appreciably the scattering processes, leading, for example, to an intense scattering for plasma ions. Thus, a closed physical picture is obtained, in which f^R describes the electronic and ionic excitations (charge + "jacket"), and W_k describes plasmons interacting with one another via the induced radiation and the induced scattering. Such a picture is correct so long as the correlation broadenings γ_k^N are much smaller than $\omega(k)$, i.e., when $W/nT \ll 1$. The smallness of $1/N_D$ leads to a very wide range of applicability of these concepts. In addition to plasmons, photons should be included in this scheme. The point is that their appearance is inevitable in a system of sufficiently large dimensions. It is possible to subdivide the types of plasma turbulence into the following classes, depending on whether the turbulence is dissipated into a) thermal energy, b) electromagnetic radiation, c) energy of the accelerated particles. It can be shown that if the system is optically thick relative to electromagnetic dissipation processes, then its main energy goes to the fast particles, which are accelerated quite effectively to ultrarelativistic energies, and consequently start to emit high frequencies when scattered by the plasmons. These photons have a spectrum $\sim \omega^{5/2}$ in the frequency regions that are optically thick, and their action on the relativistic particles causes the latter to have a power-law spectrum $1/\epsilon^{\gamma}$. Figure 4 shows the results of a numerical solution of the equation for γ as a function of $-\log \kappa = \log(W/nmc^2)$ and $(\epsilon H/mc)/\omega_p$, which yields $0.9 < \gamma < 3$. The spectral indices $\nu = (\gamma - 1)/2$ of most radio sources lie in this interval, and the value $\gamma = 2.7$, for which, according to Fig. 3, large changes of κ and ξ produce practically no change of γ, correspond to the cosmic-ray spectrum. We emphasize that this conclusion is a necessary consequence of the developed theory of a plasma as a system of interacting elementary excitations.

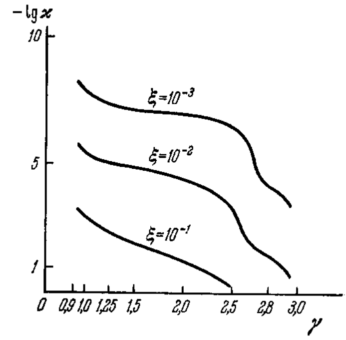

FIG. 4

[1] V. N. Tsytovich, Paper at Bucharest Conf. on Plasma Physics (1969).

[2] V. N. Tsytovich, JINR Preprint (1969).

[3] V. N. Tsytovich and B. M. Chikhachev, Astron. zh. 46, 486 (1969) [Sov. Astron. AJ 13, 385 (1969)].

Yu. B. Denisyuk, V. I. Sukhanov, Hologram Recorded in a Three-dimensional Medium as the Most Perfect Form of Image

The ability of light to depict material bodies and the associate concept of "image" are fundamental in optics. Essentially, these concepts play the role of axioms and cannot be defined in terms of categories of higher order. In this connection, the fact of representing the optical properties of an object by means of its three-dimensional hologram assumes particular importance for optics, for it is precisely the three-dimensional hologram which is the most perfect of all the presently known images[1].

Investigations performed at the State Optical Institute from 1958 through 1962 have shown that a three-dimensional hologram, by duplicating the amplitude, phase, and spectral composition of the radiation, is the optical equivalent of an object that acts on a given