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Meetings and Conferences

JOINT SCIENCE SESSION OF THE DIVISION OF GENERAL PHYSICS AND ASTRONOMY OF THE USSR ACADEMY OF SCIENCES AND THE DIVISION OF PHYSICO-MATHEMATICAL SCIENCES OF THE BELORUSSIAN SSR ACADEMY OF SCIENCES

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THE Division of General Physics and Astronomy of the USSR Academy of Sciences held a joint science session in Minsk from 6th to 10th June, 1972, with the Physico-mathematical Sciences Division of the BSSR Academy of Sciences. The following papers were presented at the session:

1. An opening address by the president and member of the Academy of Sciences of the Belorussian SSR, N. A. Borisevich.
2. N. G. Basov. Electro-ionization Lasers.
3. V. L. Ginzburg. The Development of Crystal Optics with Allowance for Spatial Dispersion.
4. Yu. N. Denisyuk. The Prospects of Optical Holography.
5. E. K. Zavoĭskiĭ. Energetics in Fast Thermonuclear Processes.
6. G. A. Smolenskiĭ. A Magnetic Memory for Future Generations of Electronic Computers.
7. N. A. Borisevich. Afterglow of Complex Molecules in the Gaseous Phase.
8. B. I. Stepanov. Lasers Based on Complex Organic Compounds.
9. F. I. Fedorov. The Theory of the Optical Activity of Crystals.
10. N. N. Sirota. Electron and Spin Density Distributions and the Physical Properties of Crystals.
11. L. I. Kiselevskiĭ. Problems of Low-temperature-plasma Spectroscopy.
12. L. V. Volod'ko. The Spectra and Kinetics of the Luminescence of the Actinides.

We publish below the content of some of the papers.

V. L. Ginzburg. The Development of Crystal Optics with Allowance for Spatial Dispersion. As is well-known, crystal optics with allowance for spatial dispersion is based on the use of the permittivity tensor $\epsilon_{ij}(\omega, \mathbf{k})$. The transition to classical crystal optics is then realized by neglecting spatial dispersion i.e., the dependence of ϵ_{ij} on the wave vector $\mathbf{k}$. Since spatial dispersion is characterized by the parameter a/λ (a is the atomic dimension or lattice constant, $\lambda = 2\pi/k$ is the wavelength), its role in optics is, in a sense, small. It is precisely for this reason that, on the one hand, the region of applicability of classical crystal optics is so wide and, on the other, allowance for spatial dispersion often turns out to be necessary only when we are dealing with qualitatively new effects. Among such spatial dispersion effects are gyrotropy (natural optical activity), the birefringence of cubic crystals, the appearance of "new" waves (e.g., in a gyrotropic medium, this is the propagation of a third wave (besides the usual two) of a given frequency in a given direction), the non-vanishing group velocity of the longitudinal waves, etc.

The beginning of the theoretical and experimental investigations of spatial dispersion effects goes back to the last century, but, in its modern form, this range of problems has been discussed mainly in the last 15—20 years—to a large extent in connection with the theory of excitons. The state of the problem before 1965 was reviewed in the monograph[1]. The purpose of the present paper is to discuss the results obtained since then, as well as the gyrotropic birefringence effect in antiferromagnetic crystals (such a possibility was pointed out back in 1963 in[2], but this paper did not come to our notice; the effect was subsequently considered in[3,4]).

In a gyrotropic medium, if we limit ourselves to terms of first order in $\mathbf{k}$,

$$\varepsilon_{ij}(\omega, \mathbf{k}) = \varepsilon_{ij}(\omega) + i\gamma_{ijl}(\omega) k_l \quad (1)$$

and similarly for $\epsilon^{-1}_{ij}(\omega, \mathbf{k})$.

On account of the symmetry principle for kinetic coefficients, $\epsilon_{ij}(\omega, \mathbf{k}, \mathbf{B}_{ext}) = \epsilon_{ji}(\omega, -\mathbf{k}, -\mathbf{B}_{ext})$ and, consequently, in (1)

$$\varepsilon_{ij}(\omega, \mathbf{B}_{ext}) = \varepsilon_{ji}(\omega, -\mathbf{B}_{ext}), \quad \gamma_{ijl}(\omega, \mathbf{B}_{ext}) = -\gamma_{jil}(\omega, -\mathbf{B}_{ext}); \quad (2)$$

here $\mathbf{B}_{ext}$ is the induction of the external magnetic field or a parameter characterizing the magnetization of the lattice or sublattice. In the absence of absorption, and for real ω and $\mathbf{k}$, the tensor ϵ_{ij} is Hermitian, on account of which $\epsilon_{ij}(\omega, \mathbf{B}_{ext}) = \epsilon^*_{ji}(\omega, \mathbf{B}_{ext})$ and $\gamma_{ijl}(\omega, \mathbf{B}_{ext}) = -\gamma^*_{jil}(\omega, \mathbf{B}_{ext})$. In the general case,

$$\gamma_{ijl} = \gamma'_{ijl} + i\gamma''_{ijl}, \quad \gamma'_{ijl} = \mathrm{Re}\, \gamma_{ijl}, \quad \gamma''_{ijl} = \mathrm{Im}\, \gamma_{ijl}.$$

On account of these relations, in a transparent, gyrotropic medium

$$\gamma'_{ijl} = -\gamma'_{jil}, \quad \gamma''_{ijl} = \gamma''_{jil}. \quad (3)$$

In a nonmagnetic medium (for $\mathbf{B}_{ext} = 0$), in virtue of (2) and (3), $\gamma''_{ijl} = 0$. Generally speaking, in a transparent magnetic medium, $\gamma''_{ijl} \neq 0$. It is precisely under the condition $\gamma''_{ijl} \neq 0$ (in particular, for a number of antiferromagnets) that the indicated gyrotropic birefringence effect exists. In its "pure" form, this effect appears in crystals which do not possess the common gyrotropy (i.e., when $\gamma'_{ijl} = 0$, or when $\gamma'_{ijl} \neq 0$, but this does not affect the propagation of the waves under consideration). It is then possible, in principle, to observe a change in the direction of the optical axes and the direction of polarization in the normal waves, the inequality of the refractive indices when the direction of propagation of the waves is reversed (when we substitude $-\mathbf{k}$ for $\mathbf{k}$), and the appearance of "new" waves near the absorption line, similar to the case of isotropic, gyrotropic media[1,5].

In spite of the fact that we are dealing with an effect which is first order in a/λ (for this reason, the region where the "new" waves can be observed is considerably broader than for a nongyrotropic medium in which the effect $\sim (a/\lambda)^2$), it was in fact possible to detect the third wave in a gyrotropic medium only by the Raman-scattering method[6,7]. It is possible that this method will prove to be applicable to the case of antiferromagnets with $\gamma'_{ijl} = 0$ and $\gamma''_{ijl} \neq 0$. Besides, the analysis of the third wave for nonmagnetic media has only just begun and should continue.

Let us say something about the experimental papers devoted to gyrotropy arising under the action of an electric field[8] and under the action of stresses[9]. With respect to the effects of order $(a/\lambda)^2$, we mention the investigation of the optical anisotropy of the cubic crystal, silicon[10]. Some distinctive features connected with wave propagation in magnetic media are elucidated in[11,12].

A special place in crystal optics with spatial dispersion and in the theory of excitons is occupied by surface phenomena and surface effects: we have in mind the various surface waves (excitons), the problem of their interaction with incident light, with phonons, and among themselves, the problem of boundary conditions, etc. It may be inferred that attention will in the near future be focused precisely in this direction[1,7,13-20], both in connection with the existence of a number of obscure and insufficiently studied aspects and in virtue of the practical importance of surface phenomena when we swi switch to miniaturized instruments and to computer elements and other devices.

Besides the problem of considering the interface in the scheme which uses the integral equation connecting the electric induction $\mathbf{D}$ and the electric field $\mathbf{E}$, as well as additional boundary conditions[1)], let us stress that it is also necessary, in taking spatial dispersion into ac-account, to specify more precisely the ordinary electrodynamic boundary conditions[3,16,17]. Let us, for example, consider the fairly general connection between $\mathbf{D}$ and $\mathbf{E}$ in an isotropic, gyrotropic medium:

$$\mathbf{D} = \varepsilon\mathbf{E} + \delta_{\mathrm{I}} \operatorname{rot} \mathbf{E} + \operatorname{rot} (\delta_{\mathrm{II}}\mathbf{E}). \qquad (4)$$

Then, as a result of the usual procedure of integrating along the direction of the normal, upon approach to a sharp vacuum-medium interface, the equation div $\mathbf{D} = 0$, for example, reduces to the boundary condition[17]

$$D_{2n} - D_{1n} - \delta_{\mathrm{II},2} \operatorname{rot}_n \mathbf{E}_2 = \varepsilon E_{2n} - E_{1n} + \delta_{\mathrm{I},2} \operatorname{rot}_n \mathbf{E}_2 = 0. \qquad (5)$$

As for the field equation curl $\mathbf{B} = (1/c)\partial\mathbf{D}/\partial t$, for the relation (4), it reduces to the boundary condition

$$[\mathbf{n}, \mathbf{B}_2 - \mathbf{B}_1] = \frac{\delta_{\mathrm{II},2}}{c}\left[\mathbf{n}, \left(\frac{\partial \mathbf{E}}{\partial t}\right)_2\right]. \qquad (6)^*$$

In view of the presence of a transition layer on the surface of a medium, it is difficult to use for the determination of the coefficients δ_{I} and δ_{II} the more accurate boundary conditions and, for example, the formulas obtained with the aid of these conditions for the polarization of the reflected light (see[18a] and the literature cited there, as well as[18b]). The effect of the gyrotropy and the transition layer on the ellipticity of the reflected light is however distinct and depends on the polarization of the incident light, and this opens up certain possibilities for an experimental discrimination of the two effects[19][2)].

What interests the speaker most, however, is not the problem of the boundary conditions, their influence on the reflection of light, etc., but the study of the indicated problems of surface excitons, their excitation and decay (including their annihilation when they interact with each other and with other types of excitons), etc. We must here bear in mind that for surface excitons allowance for spatial dispersion plays a decisive role in certain cases[1,13]. Surface excitons have on the whole still not been sufficiently well investigated: it is even not clear what types of surface excitons can occur under real conditions (in particular, the possibility of the existence of the Wannier-Mott type of surface excitons, i.e., electron-hole bound states localized near the surface, comes to mind; we have as yet not been able to find anything in the literature that indicates that such a possibility has been investigated). For surface excitons there arises, among others, the question of the possibility of formation of biexcitons, or "drops," similar to those discussed for the three-dimensional case[21]. Just as interesting for surface excitons is the problem of Bose condensation and superfluidity (the question is, in particular, the quasi-condensation for a surface of finite dimensions; it must be borne in mind, moreover, that for an infinite surface instead of a long-range order a singularity may appear in the correlation function[22]). Surface excitons may play a major role in the analysis of superconductivity—in particular, the surface-type superconductivity[15,23,24] (as obtains in superfluid or superconducting systems of the three-dimensional type, there cannot be long-range order for two-dimensional systems; this, however, does not yet inhibit, in principle, the possibility of the appearance of two-dimensional superfluidity and superconductivity, or of an effective, although not complete, disappearance of resistance in connection with the finiteness of the system, the formation of metastable states, and the appearance

[1)] The introduction of additional boundary conditions is only an approximate device which allows the use of the tensor $\epsilon_{ij}(\omega, \mathbf{k})$ in the solution of certain boundary-value problems, i.e., in a bounded medium; see [1] Sec. 10, as well as [20] (note that the conclusion drawn in [20] about the additional boundary conditions is virtually the same as the one arrived at in the book [1]; therefore the contrast of [20] and [1] contained in the former papers seems to us to have been based on a misunderstanding).

$^*[\mathbf{n}_1, \mathbf{B}_2-\mathbf{B}_1] \equiv \mathbf{n} \times (\mathbf{B}_2-\mathbf{B}_1)$.

[2)] During the session F. I. Fedorov and the author had a discussion on the question as to whether or not the coefficients δ_{I} and δ_{II} are interpendent. If we require that no energy be liberated at an interface for waves of any polarization (in particular, for circularly polarized waves), then we in fact obtain the condition $\delta_{\mathrm{I}} = \delta_{\mathrm{II}}$, used by F. I. Fedorov. Thus, this condition has a definite physical meaning. It seems to us, however, that in the general case, at the boundary of media with spatial dispersion, the energy of an incident wave can be released and be converted, for example, into some surface or nonelectromagnetic volume waves (see, in this connection, [25]). Therefore, in the framework of the phenomenological approach the condition $\delta_{\mathrm{I}} = \delta_{\mathrm{II}}$ is not obligatory, although it is possibly observed in some cases.

of singularities in the correlation function of the phase of the superconducting "wave function" at different points[22,24]).

The problems touched upon at the end of the report are not sufficiently clear, but are mentioned here in order to draw attention to them and to emphasize the necessity for carrying out a wide range of theoretical and experimental investigations connected with surface excitons.

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E. K. Zavoĭskiĭ. Energetics in Fast Thermonuclear Processes. If we were to speak about the immediate prospects of thermonuclear power, the year 2000 is the year we should have in mind. It is estimated that by this time the world's demand for all forms of fuel will be 10^{21} J/year. With that end in view, we shall probably have to construct 1000, 3×10^{10}-W thermonuclear plants. A plant of such power will burn ~ 1 cm^3 of D-T mixture per second.

According to current ideas, a stationary thermonuclear plant of such power must have a confining magnetic field of not less than 10^5 G for a plasma of density 10^{15} cm^{-3} at a temperature of 10^8 degrees. Hence, we find the volume of the plasma to be 3×10^9 cm^3. If a toroidal trap is used for the thermonuclear reactor, then the minor diameter of the torus will not be less than 10 m, and the length of the internal axis of the torus $\sim 10^2$ m. Although facilities of such scale is common, the entire gigantic chamber is filled from the beginning by a strong magnetic field, which is subsequently expelled from and pressed to the walls of the chamber by the hot plasma. Note that (for the scale) the thermal energy of the plasma of the reactor is sufficient for heating up 10 tons of copper to 1000°C. The state of the system should be stable to such a degree that the plant can operate for many years without a single sudden major violation of the equilibrium between the plasma and the magnetic field. Indeed, a rapid destruction of this equilibrium will lead to the penetration of the magnetic field into the region occupied by the hot plasma, and this will generate inside the chamber and in the solenoids producing the magnetic field surges of power equivalent to a blast of 20 tons of demolition explosives. Should such a blast destroy the wall of the torus, up to 8 g of tritium can immediately enter the atmosphere. The equilibrium can be destroyed by the development of a macroscopic plasma instability connected, for example, with "arcing," a rapid cooling of the plasma owing to local vaporization of the metal of the torus wall, stripping of metallic particles from the walls of the chamber, the breakdown of the power supply for the magnetic field (the short-circuiting of the solenoid coils), etc. Until completely reliable safeguards are found, a thermonuclear plant with magnetic confinement will be a considerable hazard for the surrounding district, and each accident on such a scale will bring about a considerable economic loss. In this situation, if we also consider the many other unsolved problems of plasma confinement and heating, then the con-