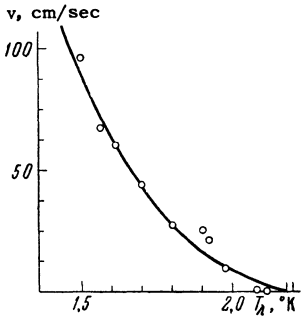

FIG. 2. Dependence of the linear flow rate of a helium film on the temperature.

During the experiment the temperature was maintained constant with an accuracy of 10^{-5} deg by an electronic stabilizer[7]. The results obtained are given in Fig. 2, which shows the temperature dependence of the flow rate of the helium film.

As is seen from the figure, the linear flow rate of a He II film increases with decreasing temperature and reaches about 100 cm/sec at 1.5° K. This surpasses considerably the critical value calculated from known values of the transport rate and film thickness[1,2] as well as the results obtained in [5]. However, it must be noted that in these investigations the stationary flow of the helium film was studied, while in the experiments described above the speed values obtained refer to the flow onto a surface free of helium. It follows from this that under such conditions the film flow rate may surpass considerably the stationary flow rate. This circumstance agrees with measurements of the thickness of a helium film flowing onto a developed surface made by Kikoin and Lazarev[6].

Such large values of the flow rate of a helium film are possibly explained by the fact that during the time of the film flow (about 0.2 sec at 1.5° K) vortices do not have time to develop strongly enough and consequently to produce friction forces to slow down the film. It is also not excluded that the circumstance that the film must form a normal component as it moves may play a certain role in these phenomena. The experiments conducted at present will probably help to obtain more detailed information on this interesting question.

We use the occasion to thank V. D. Krasnikov for producing the booster, and N. N. Mikhaĭlov for supplying lead brass wire.

[1] J. G. Daunt and K. Mendelson, Proc. Roy. Soc. **A170**, 423 and 439 (1939).

[2] K. R. Atkins, Proc. Roy. Soc., London **A203**, 240 (1950).

[3] L. C. Jackson and D. G. Henshaw, Phil. Mag. **41**, 1078 (1950).

[4] J. G. Daunt and R. S. Smith, UFN **57**, 93, 1955.

[5] J. C. Dillinger. Conference de physique de basses temperatures, Paris, p. 97, 1955.

[6] A. K. Kikoin and B. G. Lazarev, Nature **142**, 289 (1938).

[7] V. D. Krasnikov, PTÉ (in print).

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STANDING MAGNETOPLASMA WAVES IN BISMUTH SINGLE CRYSTALS

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THE possibility of propagating electromagnetic waves in a metal located in a strong magnetic field has been considered theoretically by Konstantinov and Perel'[1] and by Skobov and Kaner,[2] who showed that slightly damped waves may be propagated under the following conditions: that the Larmor radius is smaller than the wavelength in the metal, that the Larmor frequency is higher than the wave frequency, which is in turn much higher than the collision frequency. The latter condition ($\omega\tau \gg 1$) essentially distinguishes these waves, which we shall call magnetoplasma waves, from magnetohydrodynamic Alfven waves ($\omega\tau \ll 1$).

Indirect proof of the existence of magnetoplasma waves of microwave frequency in bismuth has been obtained by several authors.[3-6] The excitation of low-frequency magnetoplasma waves has been observed in several metals[7-10] having about one electron per atom (the term "magnetoplasma resonance" was introduced in [8]). Very recently there appeared a brief communication by Kirsch[11] on the observation of standing waves in bismuth for the case $\mathbf{H} \parallel \mathbf{N} \parallel C_2$ (i.e., P-waves, see below).

Some results of a detailed investigation of microwave-frequency magnetoplasma waves, excited

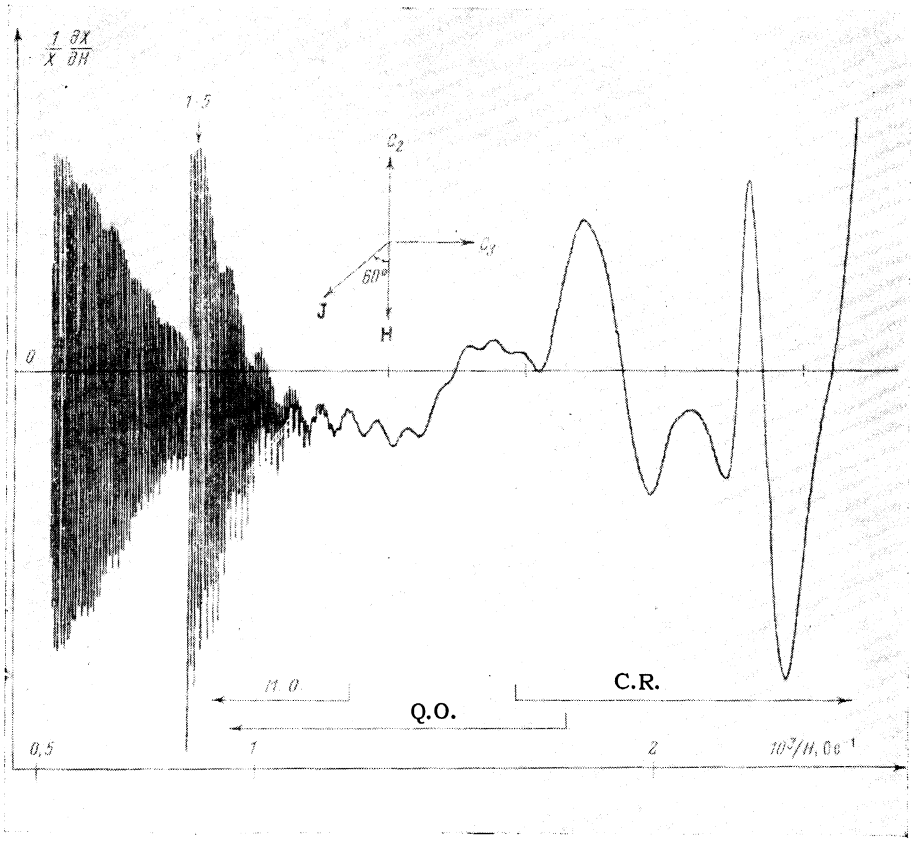

FIG. 1. Traces of cyclotron resonance (C.R.), quantum oscillations (Q.O.), and magnetoplasma oscillations (M.O.) of the surface reactance X of bismuth. The orientations of the crystal axes C_2 and C_3, magnetic field **H**, and high-frequency currents **J** in the plane of the sample surface are shown in the figure. The symbol 1:5 denotes the point at which the amplification of the circuit was altered by a factor of 5.

in plane-parallel single crystals of bismuth, are given below. The appearance of standing waves is manifested in the form of oscillations of the surface impedance of the bismuth on variation of the magnetic field, as reported earlier.[12] This method of observation proved directly the existence of magnetoplasma waves and permitted a detailed study of their properties. The present experiments were carried out at frequencies of 9.5 and 25 kMc on bismuth single crystals[12] in the form of disks of 18 mm diameter and 0.5—1.7 mm thickness, at a temperature of 1.8° K in a magnetic field H = 0.5 — 10 kOe. The surface impedance was measured by the frequency modulation method[13] and by the power transmission coefficient method[14] for high oscillation amplitudes.

Figure 1 shows the nature of the variations of the surface impedance of bismuth as a function of H^{-1} in a field parallel to the sample surface. Magnetoplasma oscillations were observed for any orientation of the vector **H**; we shall call them S-oscillations and the corresponding magnetoplasma waves will be termed S-waves. S-oscillations also exist when the angle ϑ (the angle between **H** and **N**, where **N** is the normal to the sample surface) is reduced to 80—70°. For $\vartheta \approx 85°$ oscillations of different period ΔH^{-1} appear and they exist at any ϑ; we shall call them P-oscillations, with P-waves corresponding to them. Depending on the polarization of the high-frequency current, the two waves may be excited with different velocities of propagation.

S-oscillations exhibit the following characteristic properties. Their amplitude is least when **H** ∥ **J** (**J** is the high-frequency current vector) and increases on increase of the angle between **H** and **J**. In the intervals between the main minima there are, as for example in Fig. 1, additional minima of lesser depth, which almost disappear when **H** ∥ **J**. The period $\Delta_S H^{-1}$, determined from the main minima, depends weakly on the field when **H** ∥ C_2 and decreases by a factor of approximately 1.5 when the field is changed from 0.5 to 10 kOe in the case **H** ∥ C_3. Rotation of the field **H** from C_2 to C_3 leads to an increase of the period by a factor of 1.5—2; the anisotropy of ΔH^{-1} in the basal plane amounts to ≈ 8%.

Assuming that oscillation number n (starting from $H^{-1} = 0$) corresponds to the excitation of a standing wave of order n, we then have $n\lambda/2 = D$, because the wave velocity **v** ∥ **N**. The period $\Delta_S H^{-1}$ is independent of H^{-1} (in fields H > 2 kOe this is correct to within the experimental error), and therefore $n = H^{-1}/\Delta_S H^{-1}$. Consequently we

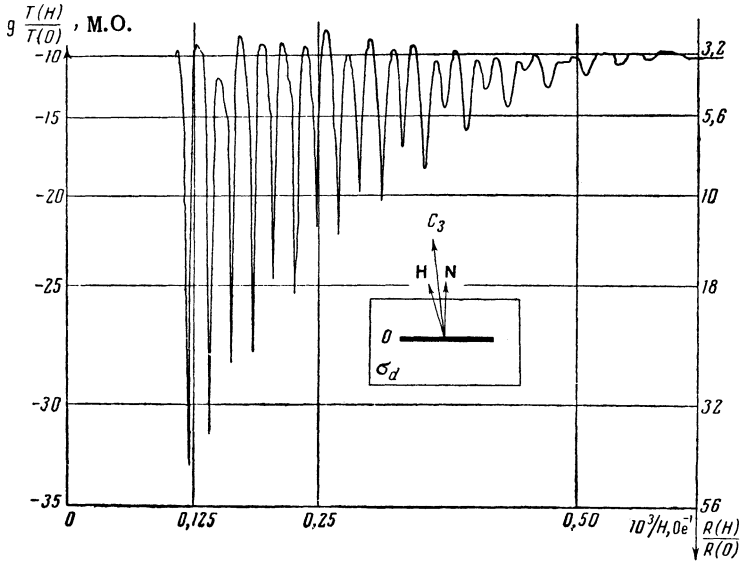

FIG. 2. Trace of magnetoplasma P-oscillations of the surface resistance R of bismuth. T is the coefficient of power transmission through the resonator. The axis C_3 and the field **H** lie in a diagonal plane σ_d of the crystal, which is perpendicular to the crystal surface and is denoted by the line 0. $\angle$ N, C_3 = 4°; $\angle$N, H = 15°.

find that

$$vH^{-1} = 2Df\Delta_S H^{-1}, \qquad (1)$$

where f is the wave frequency. The right-hand part of Eq. (1) is found from the experimental data. For example, when $\mathbf{H} \parallel C_2$ for samples with $\mathbf{N} \parallel C_3$ it amounts to $(2.34 \pm 0.05) \times 10^4$ cm/sec. Oe, and for samples with $\mathbf{N} \perp C_3$ it is equal to $(1.86 \pm 0.04) \times 10^4$ cm/sec.Oe. Hence the numerical characteristics of S-waves (from observations in fields $H \lesssim 10$ kOe!):

$$v_S \approx (2 - 50) \cdot 10^7 \text{ cm/sec};$$
$$\lambda_S \approx 0.02 - 0.5 \text{ mm}, \quad n \approx 5 - 100.$$

The experimentally established proportionality of the period $\Delta_S H^{-1}$ and the quantity $(Df)^{-1}$ and the dependence of the period on the orientation of **N** proves that the oscillations described here are due to the excitation of standing waves in the crystal.

P-oscillations, of which a sample record is given in Fig. 2, have the following properties. Their amplitude rises almost monotonically on decrease of ϑ; the existence of additional minima can be seen in Fig. 2. The period $\Delta_p H^{-1}$ for direction of **H** close to the axis C_3, decreases by a factor of 3 on increase of H from 1 to 8 kOe; for other directions of **H** the period is weakly dependent on H. In experiments on a sample with $\mathbf{N} \parallel C_3$ the period $\Delta_p H^{-1}$ exhibits a dependence on the angle $\vartheta = \angle \mathbf{H}$, $\mathbf{N} = \angle \mathbf{Hv}$, of the form $\Delta_p H^{-1}(\vartheta) = \Delta_p H^{-1}(0) \cos \vartheta$ with the exception of the interval $\nu \lesssim 30°$ in which a strong anisotropy of $\Delta_p H^{-1}$ appears. Assuming the equality (1) to be valid for P-waves, we obtain the P-wave velocity $v_p = v \cos \vartheta$, where v is an anisotropic function proportional to H. This makes it possible to write the dispersion law for P-waves in the form

$$\omega_P = A\,(\mathbf{k}_P \mathbf{H}),$$

where $\mathbf{k}_p$ is the wave vector. The numerical values of v_P and λ_P are close to v_S and λ_S.

The following experiment demonstrates strikingly the transparency of bismuth single crystals to magnetoplasma waves: if another sample is placed against the outer surface of a sample which is acting as the resonator wall, the form of the observed oscillations changes significantly.

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[1] O. V. Konstantinov and V. I. Perel', JETP **38**, 161 (1960), Soviet Phys. JETP **11**, 117 (1960).

[2] V. G. Skobov and É. A. Kaner, JETP in press.

[3] S. J. Buchsbaum and J. K. Galt, Phys. Fluids **4**, 1514 (1961).

[4] J. Kirsch and P. B. Miller, Phys. Rev. Lett. **9**, 421 (1962).

[5] P. B. Miller and R. R. Haering, Phys. Rev. **128**, 126 (1962).

[6] G. A. Williams, Bull. Am. Phys. Soc., ser. II **7**, 409 (1962); **8**, 205 (1963).

[7] Bowers, Legendy, and Rose, Phys. Rev. Lett. **7**, 339 (1961).

[8] Rose, Taylor, and Bowers, Phys. Rev. **127**, 1122 (1962).

[9] Cotti, Wyder, and Quattropani, Phys. Lett. **1**, 50 (1962).

[10] Taylor, Merrill, and Bowers, Bull. Am. Phys. Soc., ser. II **8**, 65 (1963).

[11] J. Kirsch, Bull. Am. Phys. Soc., ser. II **8**, 205 (1963).

[12] Khaĭkin, Mina, and Edel'man, JETP **43**, 2063

(1962), Soviet Phys. JETP **16**, 1459 (1963); Paper presented at the Ninth All-Union Conference on Low-Temperature Physics, Leningrad, June, 1962.

[13] M. S. Khaĭkin, PTÉ No. 3, 95 (1961).

[14] R. T. Mina, JETP **40**, 1293 (1961), Soviet Phys. JETP **13**, 911 (1961).

Translated by A. Tybulewicz
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THE USE OF A LASER IN THE INVESTIGATION OF THE COMBINATION SCATTERING SPECTRA OF COLORED POWDERS

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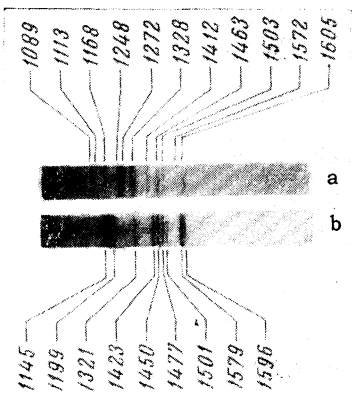
THE spectral investigation of combination scattering of powders is fraught with remarkable difficulties associated with the small effective transparency of the object, the large scattering of the exciting light, etc. In the case of colored powders these difficulties are aggravated since the characteristic absorption of the object does not allow examination in the commonly used spectral region (4000—5000 Å). In this case it would be advantageous to carry out investigation in the yellow and red spectral regions. Existing sources for the excitation of combination scattering in the long wavelength region (helium, cadmium lamps, etc.) are not completely satisfactory since either they do not have sufficient intensity or interfering lines and a certain continuous background are present in the spectrum.

The advent in recent times of new sources of monochromatic radiation—lasers in the optical region—is of unusual importance for the present problem. The advantages of this source for the excitation of combination scattering spectra (the presence of a single narrow line and high power) have been discussed in the literature many times, but there has been only one paper on its experimental realization.[1]

A ruby laser, which gives a line at 6943 Å, i.e., in the red, is by far the most suitable one for our problem.

For our investigation we used a grating spectrograph having 600 lines/mm with the ruled part 140 × 150 mm in extent. Identical, f 1, 250 mm objectives were used in the collimator and the camera. The work was carried out in the first order at a dispersion of 62 Å/mm. Infra-760 plates and Infrarapid-750 film were used to record the spectra. In photographing the spectra of the powders we used the simplest method—exposure "by transmission." A cuvette containing the substance under investigation was placed directly before the slit of the apparatus. The exciting light was focused on the samples by means of a condensing lens. This arrangement allowed the most complete use to be made of the large aperture of the instrument, since the light passing through the powder is in a very large solid angle.

A ruby laser operating at low power was used as the source. The energy in the flash from the pumping lamp varied between 1.0 and 1.8 kJ. The crystal was cooled in a stream of vapors from liquid nitrogen. In order to eliminate parasitic light the source was placed at a distance of 2 m from the cuvette containing the sample. From 30 to 100 flashes were needed to obtain a recording of the spectra, using a slit width of 0.07—0.1 mm, which in this region is equivalent to 8—12 cm^{-1}.



Combination scattering spectra obtained by excitation with a ruby laser; a – 4,4'-azoxyanisole; b – anisal-para-amino-azobenzene.

The combination scattering spectra of a number of powders were obtained. By way of illustration we show the spectra of 4,4'-azoxyanisole, a bright yellow powder, and anisal-para-aminoazobenzene, a red powder.

On the basis of our results we conclude that the ruby laser is a very valuable tool for the investigation of combination scattering spectra of colored powders.