smaller widths is clearly visible in the left-hand parts of the curves in Fig. 1 (the fields H_1 and H_2).

Local penetrations of the electromagnetic field into the interior of a metal were predicted theoretically by Azbel';[4] however, he discussed only the high-frequency case when the electrons that contribute to this effect take part in cyclotron resonance. Therefore Azbel's theory is not directly applicable to our experiments although the phenomenon dealt with by him and our effect are very similar.

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THE COHERENCE AND DIRECTIVITY OF EMISSION FROM A RUBY LASER

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THE directivity of the emission from a ruby laser is usually worse than the diffraction limit set by the dimensions of the crystal. This is caused by the optical imperfection of the crystals. Nelson and Collins[1] have shown that the emission is coherent over small regions of the end faces of the crystal. It was assumed that diffraction at the boundaries of these regions also caused angular divergence of the generated beam. However, as was shown by Masters and Parrent,[2] the radiation is coherent in sections that are separated by more than 3 mm from each other.

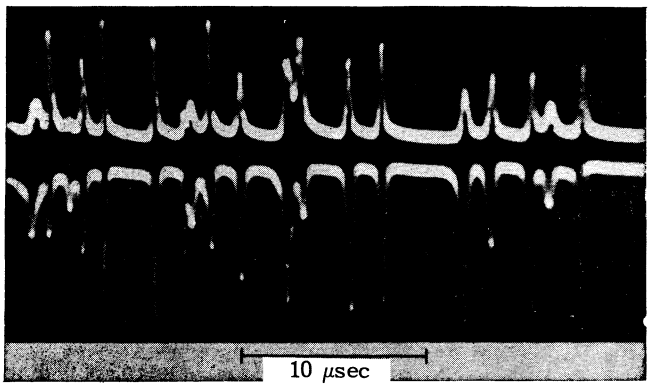

FIG. 1. Oscillogram of the emission from two sections of the end face of a ruby laser crystal.

The purpose of the experiments described below was the investigation of the relation between the coherence and directivity of the emission from a ruby laser. First of all, it was shown that the pulsations of the emission during generation arise simultaneously in all radiating surfaces of the crystal. Figure 1 shows an oscillogram obtained from photomultipliers which received radiation from two different sections of the crystal separated by 2 mm. As can be seen from the figure, the pulses of the radiation always originate simultaneously in different parts of the crystal, although sometimes a difference in relative intensity of the peaks is observed.

For the investigation of coherence, the following interference experiments were carried out. The end face of the crystal was focused by an objective O_1 on a diaphragm D consisting of two or five apertures (Fig. 2). The objective O_2 forms an image of the principal focal plane of objective O_1 on the photographic plate F. Thus, each point of the image corresponds to rays leaving the crystal in a specific direction.

The pattern obtained in the absence of diaphragm D differed for different crystals and was characteristic of the directivity of the crystal as a whole. An example of such a pattern for one of the crystals is shown in Fig. 3. Upon insertion of the two-hole diaphragm the intensity distribution on F changed drastically, and, in addition, interference bands were observed. The five-hole diaphragm gave a complex interference pattern that could be observed particularly well in the somewhat more distant plane F_1. Interference of the

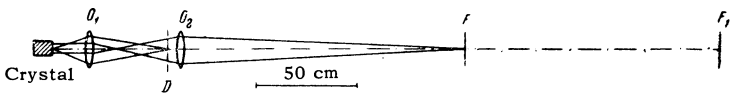

FIG. 2. Arrangement for observing interference.

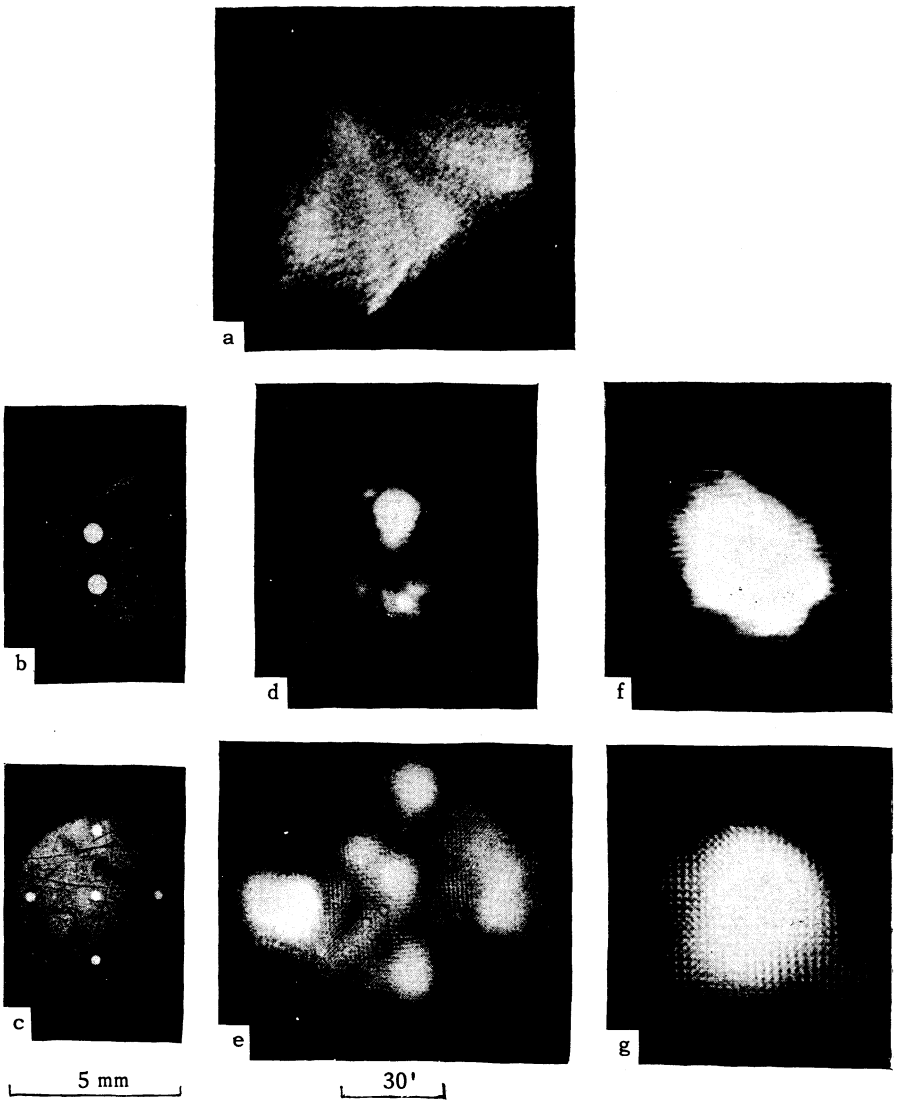

FIG. 3. a – pattern in plane F without diaphragm D; b – configuration of the two-hole diaphragm with respect to the image of the end face of the crystal; c – the same for the five-hole diaphragm; d, e – pattern in plane F for the two-hole and five-hole diaphragms, respectively; f, g – pattern in plane F_1 for the two-hole and five-hole diaphragms, respectively.

radiation emitted from different, widely separated sections proves that practically the entire end face of the crystal radiates coherently. At the same time the intensity distribution on F from two holes indicates that the direction of rays emanating from different points of the crystal is different; in other words, the wave-front is not plane. Evidently, it is just this circumstance that limits the directivity of the radiation in the majority of cases.

We also observed, as did Masters and Parrent,[2] that the emission from some crystals gave a pattern of rings (see Fig. 4). The appearance of such a ring pattern is not directly connected with the coherence of the emission. Indeed, it is possible that crystals giving a good interference from two holes will not show a ring pattern. Ring patterns apparently appear in those cases when the radiated waves are sufficiently plane, whereby the k-th ring corresponds to the condition $2nl\cos\theta_k = (m-k)\lambda$, where l is the length of the crystal, n is the refractive index, and θ_k is the angle between the normal to the wave front

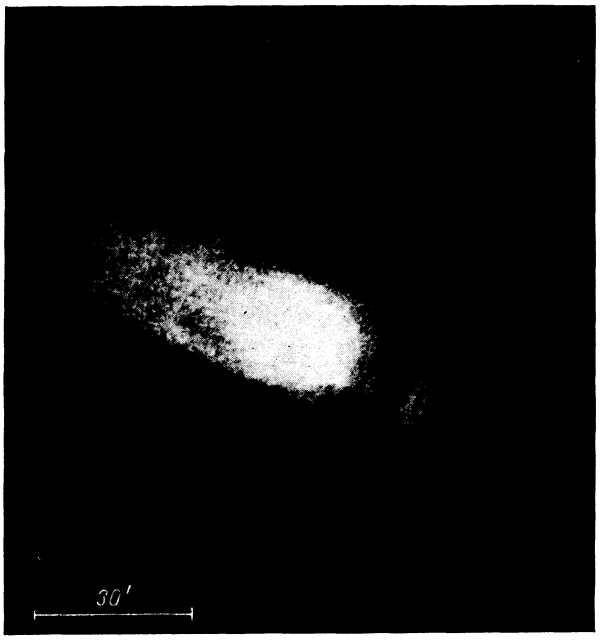

FIG. 4. Ring pattern in the focal plane of the objective (different crystal).

inside the crystal and the normal to the plane of the end face. Measurement of the diameters confirms this relation.

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A CERTAIN INEQUALITY FOR THE EFFECTIVE MASS IN METALS WITH LOW CARRIER DENSITIES

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In pure metals with low carrier densities the number of negative carriers is equal to the number of positive ones. This is a direct consequence of the law of charge conservation. At sufficiently low carrier densities the distances between carriers are very great and the interaction between them is essentially of Coulomb type. It is known, however, [1] that in the attractive-field potential, which decreases as $1/r$ at infinity, there are always energy levels corresponding to the bound states; consequently positive and negative charges recombine into electrically neutral entities which cannot carry the current.

At high carrier densities the potential of each charge is screened by the Debye-Hückel cloud and is of short-range type. When the screening radius is sufficiently small there are no bound states at all in the corresponding potential well and transport of charge is thus possible. These ideas were first put forward by Mott. [2]

The order-of-magnitude condition which determines the importance of the Debye-Hückel screening is obtained by equating the mean distance between carriers ($\simeq N^{-1/3}$, where N is the number of carriers per cm^3) to the radius of the Debye-Hückel cloud r_D:

$$N^{-1/3} \sim r_D.$$

The value of r_D can easily be found from the relationship

$$\varkappa^2 = r_D^{-2} = 4\pi e^2 \sum_a \partial N_a / \partial \mu_a \sim e^2 \partial N / \partial \mu.$$

The chemical potential is $\mu \simeq \hbar^2 N^{2/3}/m^*$ (m^* is the mean effective carrier mass) and its derivative is

$$\partial\mu/\partial N \sim \hbar^2/m^* N^{1/3}.$$

Now we can easily write down the condition for metallic conduction:[1)] $N^{1/3} \gtrsim m^* e^2/\hbar^2$, i.e., at a given carrier density the effective mass m^* should satisfy the inequality

$$m^* \lesssim (\hbar/e)^2 N^{1/3}.$$

It is convenient to divide the above expression by the free-electron mass m. Allowing for the fact that the lattice parameter a is of the same order of magnitude as the Bohr radius $\hbar^2/me^2$, we can write

$$m^*/m \lesssim n^{1/3}, \qquad (1)$$

where $n = Na^3$ is the density of carriers per atom.

The formula obtained indicates that metals in which the effective carrier mass is of the order of the free electron mass should always have high carrier density. [3] Metals with low carrier density should always have small effective carrier mass.

In the case of graphite and bismuth the carrier density is $n \simeq 10^{-5}$ and the effective carrier masses are of the order of several hundredths of the free electron mass. Thus our relationship is fully satisfied qualitatively. Since graphite and bismuth have very complex and anisotropic electron spectra, we can expect only very rough quantitative agreement.

The inequality derived here is a selection rule. Materials in which the effective carrier masses do not satisfy the inequality cannot be metals with low carrier density.

It is necessary to make the following point. Let us assume that a nonmetallic crystal with a known electron spectrum is deformed so that the gap between the valence and conduction bands decreases. When the band overlap is small we should have a metal with low carrier density. However, the theorem proposed here indicates that band overlap is