3. It follows from (5) and (6) that in weak fields ($\alpha \to 0$) the dissociation constant is actually proportional to the radiation flux density. On the other hand, in strong fields ($\alpha \to \infty$), the vibrational "temperature" and the dissociation constant tend to a finite limit, corresponding to a bleaching of the system, connected with the saturation effect. In conclusion, we present numerical calculations for a case close to the experimental conditions of [6, 7], i.e., $t_c \simeq 10^{-6}$ sec, $t_m \simeq 10^{-3}$ sec, $\hbar\omega \simeq 0.1$ eV, $\mathcal{E}^* \simeq 2$ eV, $\sigma \simeq 10^{-17}$ cm^2 (pressure $\sim$100 Torr), $I \simeq 10^2$ W/cm^2. Then $\theta \simeq 0.2$ eV and $\gamma \simeq 10^3$ sec^{-1}. Thus, $\gamma t_m \sim 1$ under these conditions, and consequently a noticeable fraction of the molecules will be dissociated prior to the onset of the vibrational-translation relaxation.

Obviously, the results can be directly applied to the case of decay, resulting from a chemical reaction, of a vibrationally excited molecule. In formulas (5) and (6) it is then necessary to take $\mathcal{E}^*$ to mean an energy close to the activation energy of the chemical reaction.

[1] G.A. Askar'yan, Zh. Eksp. Teor. Fiz. 46, 403 (1964) [Sov. Phys.-JETP 19, 273 (1964)].
[2] F.V. Bunkin, R.V. Karapetyan, and A.M. Prokhorov, ibid. 47, 212 (1964) [20, 142 (1965)].
[3] G.A. Askar'yan, ibid. 48, 666 (1965) [21, 439 (1965).
[4] A.N. Oraevskii and V.A. Savva, Kratkie soobshcheniya po fizike (FIAN) (Brief Communications in Physics) 7, 50 (1970).
[5] F.V. Bunkin and I.I. Tugov, Zh. Eksp. Teor. Fiz. 58, 1987 (1970) [Sov. Phys.-JETP 31, 1071 (1970)].
[6] N.V. Karlov, Yu.N. Petrov, A.M. Prokhorov, and O.N. Stel'makh, ZhETF Pis. Red. 11, 220 (1970) [JETP Lett. 11, 135 (1970)].
[7] N.D. Artamonova, V.T. Platonenko, and R.V. Khokhlov, Zh. Eksp. Teor. Fiz. 58, 2195 (1970) [Sov. Phys.-JETP 31, 1185 (1970)].

INFLUENCE OF NONEQUILIBRIUM EXCITATIONS ON THE PROPERTIES OF SUPERCONDUCTING FILMS IN A HIGH-FREQUENCY FIELD

B.I. Ivlev and G.M. Eliashberg
Institute of Theoretical Physics, USSR Academy of Sciences

Submitted 18 March 1971
ZhETF Pis. Red. 13, No. 8, 464 - 468 (20 April 1971)

A number of experiments have revealed a certain increase of the critical current of thin films [1, 2], and also of their transition temperature [3] under the influence of a high-frequency field. As already noted [4], effects of this type may be due to a redistribution of the electronic excitations, which inevitably occurs under conditions of stationary irradiation. What remained uncertain, however, was the possible scale of the effect, since the calculations were made only in first order in the field intensity. The results presented below fill this gap.

We used for the calculation a model in which the film was assumed to be so thin that the density of the high-frequency current in the energy gap Δ remained constant over its cross section. At the same time we assumed that the mean free path of the electron is small compared with the film thickness, making it unnecessary to take into account the singularities due to reflection from the walls.

The principal role is played in what follows by the assumption that the lifetime of the excitation τ_0 is large in relation to the energy transfer. In the case of a metal at $T \ll \theta$ (the Debye temperature) this time, as is well known, is equal to $\tau_0 \sim \min\{\hbar\theta^2/T^3, \hbar E_F/T^2\}$, so that $\tau_0 \sim 10^{-8} - 10^{-9}$ sec when T is of the order of the temperature of the superconducting transition[1]. All the quantities with the dimension of energy (T, Δ, $\hbar\omega$) are assumed to be quite large compared with $\hbar\tau_0^{-1}$. In particular, the inequality $\omega\tau_0 >> 1$ makes it possible to neglect the high-frequency oscillations of Δ, and to consider only an excitation distribution function $n(\varepsilon)$ that is diagonal in the energy. This function, as can be shown, is determined under the foregoing conditions by the kinetic equation ($h = 1$ in all the intermediate formulas)

$$I_\epsilon\{n\} = 2\alpha\{U_-(n_{\epsilon-\omega} - n_\epsilon) - U_+(n_\epsilon - n_{\epsilon+\omega}) + V(1 - n_\epsilon - n_{\omega-\epsilon})\},$$

$$U_\mp = \frac{\epsilon(\epsilon \mp \omega) + \Delta^2}{\sqrt{(\epsilon - \omega)^2 - \Delta^2}} \frac{\theta(\epsilon \mp \omega - \Delta)}{\epsilon}; \quad V = \frac{\epsilon(\omega - \epsilon) - \Delta^2}{\sqrt{(\omega - \epsilon)^2 - \Delta^2}} \frac{\theta(\omega - \Delta - \epsilon)}{\epsilon}. \tag{1}$$

where $\alpha = (1/\pi)D(e/c)^2 A_\omega A_{-\omega}$, A_ω is a vector potential of the field inside the film, $D = \ell w/3$ is the diffusion coefficient of the electron in the normal state. The first two terms of the right-hand side correspond to absorption of a field quantum by the existing excitations, and the last term describes the production of the pair of excitations $\omega > 2\Delta$. The parameter Δ is determined by the BCS equation with a non-equilibrium function $n(\varepsilon)$[2]:

$$\Delta = \lambda \int_\Delta^{\omega_D} \frac{d\epsilon}{\sqrt{\epsilon^2 - \Delta^2}} [1 - 2n(\epsilon)] . \tag{2}$$

In the vicinity of T_c, to which all the results presented below are referred, Eq. (2) takes the form

$$\frac{T_c - T}{T_c} - \frac{7\zeta(3)}{8\pi^2}\left(\frac{\Delta}{T_c}\right)^2 + \frac{\Delta}{T_c} F ; \qquad F = - \frac{2T}{\Delta} \int_\Delta^\infty \frac{d\epsilon}{\sqrt{\epsilon^2 - \Delta^2}} n_1(\epsilon), \tag{2'}$$

where $n_1(\varepsilon)$ is the non-equilibrium part of $n(\varepsilon)$. As will be shown later, $n_1(\varepsilon)$ is concentrated when $\Delta << T_c$ in the energy region $\varepsilon - \Delta \sim \Delta << T_c$, and therefore, as can be shown, the relaxation-time approximation is applicable:

$$I\{n\} \approx 2\gamma n_1(\epsilon) , \tag{3}$$

where $\gamma = \hbar\tau_0^{-1}$. On the other hand, if the field is sufficiently strong and $\omega << \Delta$, then the interval of variation of $n_1(\varepsilon)$ turns out to be large compared with ω. This makes it possible to reduce (1) - (3) to a differential equation

$$N'' - \frac{y^3}{(y^2 + 2)\sqrt{y^2 + 1}} \beta N = \frac{y}{(y^2 + 2)\sqrt{y^2 + 1}} ,$$

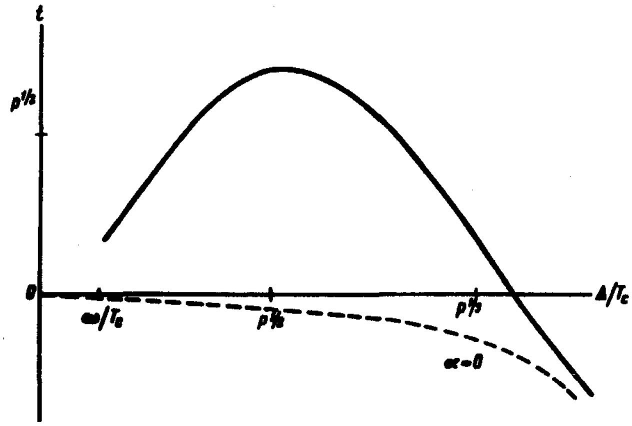
---

[1] For a thin film in a stream of helium, τ_0 may turn out to be much smaller: upon reflection from the wall, the electron may transfer energy directly to the helium, whose Debye temperature is much lower than that of the metal. One can therefore expect a large magnitude of the effect to be observed if the film is not in direct contact with the helium.

[2] It can be shown that under the conditions in question the action of the field reduces mainly to a change of $n(\varepsilon)$.

$$y = \frac{\sqrt{\epsilon^2 - \Delta^2}}{\Delta}, \quad N(y) = \frac{2T}{\Delta}\int_0^y n_1(y')dy', \quad \beta = \frac{\gamma\Delta^2}{\alpha\omega^2}, \tag{4}$$

which must be solved under the conditions $N(0) = N(\infty) = 0$. The last of these conditions means conservation of the total number of excitations, as is the case in the approximation (3). To investigate (2') it suffices to consider (4) in the limiting cases of large and small values of β. At a specified frequency and field intensity (ω, α) this corresponds to values $(\Delta/T_c) \gg p^{1/2}$, $(\Delta/T_c) \ll p^{1/2}$, where $p = \alpha\omega^2/\gamma T_c^2$. In these cases the solution of (4) can be obtained in analytic form. It leads to the following results:



$$n_1(y) \approx \begin{cases} -\dfrac{\Delta}{4T}\left(\dfrac{2}{\beta}\right)^{2/5} & y \ll \beta^{-5/4} \\[2ex] \dfrac{\Delta}{\beta T}\,\dfrac{1}{y^3} & y \gg \beta^{-5/4} \end{cases}; \quad F \approx \frac{5}{4}\,\frac{\ln\beta}{\beta}, \quad \beta \gg 1, \tag{5}$$

$$n_1(y) \approx -\frac{\Delta}{2T}\left\{\frac{\pi}{2} - \operatorname{arc\,tg}\sqrt{y^2+1} + n'\right.; \quad F \approx 1{,}3\,, \quad \beta \ll 1, \tag{6}$$

where n' is a slowly varying function of small amplitude, $\sim\sqrt{\beta}$, which is of no importance in the calculation of F. We note that both cases, (5) and (6), can be considered without going outside the framework of the condition $\omega \ll \Delta \ll T$, if α and ω are bounded by the inequalities

(7)

When $\Delta \sim \omega$ the transition from (1) to (4) is no longer valid.

The dependence of $t = (T - T_c)/T_c$ on Δ/T_c, determined by (2), (5), and (6), is shown schematically in the figure. The characteristic scale here is the quantity $p = \alpha\omega^2/\gamma T_c^2$, and in accordance with (7) we have $p \ll 1$. We see that the transition to the normal state should have a jumplike character. The maximum of the curve determines the upper limit of the existence of a superconducting state (at least as a metastable state), $t_{max} \sim p^{1/2}$. At the maximum point $\Delta/T_c \sim p^{1/2}$, and at $T = T_c$ we have $\Delta \sim p^{1/3}$. Extrapolating these results to the values $p \sim 1$, we see that in this case $t_{max} \sim T_c$ and $\Delta(T_c) \sim \Delta(0)$. When $p \sim 1$ the results are not valid even qualitatively. In this case it is necessary to forego the relaxation-time approximation.

To describe the required field intensity, we note that $\alpha \sim \gamma$ corresponds to an incident wave (H_ω) with amplitude of the order of the static critical field at $T_c - T \sim \gamma \sim 10^{-2} - 10^{-3}$°K. The field frequency ω, on which the parameter p depends, is proportional to the square of the electric field in the film, and it is desirable to choose it as large as possible. The upper limit is imposed by the requirement $\omega < 2\Delta$ in the entire proposed interval of variation of Δ.

We take the opportunity to thank L.P. Gor'kov and E.I. Rashba for important remarks, and to the authors of [3] for the opportunity of reading the manuscript of their article

[1] A.F. Wyatt, V.M. Dmitriev, W.S. Moore, and F.W. Sheard, Phys. Rev. Lett. 16, 1166 (1966).
[2] A.H. Dayem and J.J. Wiegand, Phys. Rev. 115, 419 (1967)
[3] V.M. Dmitriev, E.V. Khristenko, A.V. Trubitsyn, and F.F. Mende, Ukr. Fiz. Zh. 16 (1971).
[4] G.M. Eliashberg, ZhETF Pis. Red. 11, 186 (1970) [JETP Lett. 11, 114 (1970)].